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# NAVAL POSTGRADUATE SCHOOL
## Monterey, California

STUDIES AND ANALYSES IN SUPPORT OF THE
OIL ANALYSIS PROGRAM

by

T. Jayachandran
H. J. Larson

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NAVAL POSTGRADUATE SCHOOL
MONTEREY CALIFORNIA 93943

R. H. SHUMAKER
Rear Admiral, U. S. Navy
Superintendent

D. A. SCHRADY
Provost

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Results of statistical analyses of the data from the field test of a newly developed Portable Wear Metal Analyzer (PWMA) are reported. New formulas for converting readings from an atomic absorption spectrometer into equivalent readings for an atomic emission spectrometer are derived. Efforts to provide technical consultation on the development of a new software package to computerize some of the daily routine operations of oil laboratories are discussed.

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## 1. INTRODUCTION

This report contains the results of a continuing effort, supported by Kelly Air Force Base, to conduct statistical studies and analyses to support and enhance the effectiveness of the spectrometric oil analysis program (SOAP). Under this program, oil samples are drawn periodically from aircraft engines (and other oil-wetted components) and analyzed on a spectrometer to measure the amounts of certain wear metals in the samples. These measurements are used to monitor the wear-condition of the engines and to predict potential failures/breakdowns. The analysis of the oil samples and the monitoring of the aircraft engines are performed at one of about 140 Air Force laboratories dispersed all over the world.

Often, some of the aircraft are deployed for long periods of time to remote field locations; as it stands now, for these aircraft, there can be long delays between the time an oil sample is taken and the time the results are known, thus essentially losing the benefits of SOAP. For this reason, the Air Force contracted with the Perkin-Elmer Corporation for the development of a Portable Wear Metal Analyzer (PWMA). Six prototype PWMA's have been built and delivered to the Air Force for field testing in an operational environment. The Air Force Wright Aeronautical Laboratories (AFWAL) developed a field test plan and the test was conducted at three Air Force bases and one Navy laboratory during the period July-October 1985.

One of the tasks of our project is to analyze the data from the PWMA field test and provide estimates of the accuracy, repeatability and reproducibility of the PWMA and any other information relevant to the assessment of the suitability of the PWMA for SOAP. It should be pointed out that part of the funding for the task was provided by the Naval Air Engineering Center (NAEC), Lakehurst, NJ. A summary of our findings from the data analysis is in Section 2. A more detailed presentation of the results can be found in a separate technical report prepared for NAEC [1].

The oil laboratories participating in SOAP use one of two types of spectrometers (atomic emission and atomic absorption) that differ in their operating principle. In an emission spectrometer an oil sample is subjected to a high voltage spark causing the emission of light which is separated by wavelengths and converted into measurements of concentrations (ppm) of the wear metals in the sample. With an atomic absorption spectrometer the wear metals in the sample are energized by a high temperature flame causing absorption of light energy from a known source; the amount of absorbed light energy attributable to each of the wear metals of interest is measured and converted into a concentration level (ppm) for the wear metal. Because of the differences in the operating principle, the concentration measurements produced by the two types of spectrometers, for the same oil sample, can be and are quite different. For transient aircraft, that move from one base to another this could be problematic; one base may be using an atomic emission (AE) spectrometer while the other base may have an atomic absorption (AA) spectrometer. The wear metal history for the aircraft would then consist of two sets of data that are not comparable. One approach to solving this problem is to determine mathematical formulas to convert AA readings into equivalent AE readings. Currently, an approximate formula viz., AE equivalent reading = 2 x AA reading, is in use. It has been shown (see references [2] and [3] that this approximation is somewhat crude and that statistical regression techniques can provide more accurate conversion formulas. The second task of our project, reported on in Section 3, deals with new conversion formulas obtained by fitting least squares straight lines to the AA and AE readings for identical samples, extracted from the monthly correlation program summary reports.

A third task is to provide technical consultation on a new software package entitled OAP Laboratory Manager, that was being developed by the Systems Control Technology, Inc., for the Air Force, to computerize some of the daily routine functions in an oil laboratory, such as daily standardization and calibration of the spectrometer. A discussion of this effort is in Section 4.

## 2.1 PWMA FIELD TEST

The PWMA is a new portable wear metal analyzer developed for the Air Force by the Perkin-Elmer Corporation. It is designed to simultaneously measure the concentrations of nine different wear metals (Fe, Ag, Al, Cr, Cu, Mg, Ni, Si, and Ti) with an accuracy of one ppm and a repeatability of 2.5% and can be expected to withstand extremes of temperature, humidity and shock. The operation of the PWMA is fairly simple - a small oil sample is injected into a (replaceable) graphite furnance tube using an argon-propelled sample injected gun. At the push of the start button a built-in microprocessor takes control of the operation and the oil sample is atomized; a combination of a light source and a nine channel polychrometer measures the light energy absorbance attributable to each of the nine wear metals. A calibration algorithm then converts the absorbance numbers into wear metal concentration levels measured in ppm, and the results are output to a built-in thermal printer; the results can also be read off of a LED display. Initially, the PWMA needs to be calibrated to determine certain parameters of the calibration algorithm. Currently, this requires the burning of three different synthesized oil samples (calibration samples) each with known concentration levels of the nine wear metals; the microprocessor performs the necessary analysis on the concentration levels and the corresponding (light energy) absorbance numbers to determine the calibration curve. The estimated life of the graphite furnance tube is about 160 sample burns after which it needs to be replaced.

A prototype PWMA was built and successfully demonstrated in June 1984. Six copies of the prototype were purchased by the Air Force for testing in an operational environment with Air Force personnel operating the instruments. The Air Force Wright Aeronautical Laboratories (AFWAL) at the Wright Patterson Air Force Base drew up a field test plan and the test was conducted during the period July-October 1985 at three Air Forces bases (Elmendorf, Langley and Myrtle Beach) and one Navy laboratory (NARF, Pensacola); one instrument was retained by the Perkin-Elmer Corporation for use as a spare in case of a breakdown and one unit was sent to Wright Patterson Air Force Base for in-house evaluation at AFWAL. The plan called for the testing of twelve graphite tubes, with 160 sample analyses performed over a four day period (40 burns per day) on each tube, at each base. The 40 samples on any given day are composed by calibration samples, verification samples (synthesized samples similar to calibration samples with known concentration levels), correlation samples (blends of synthesized and used oil samples supplied by JOAP-TSC) and random samples (used oil samples from locally based aircraft). The PWMA is to be calibrated on the first and third days while on the second and fourth days a simpler "reslope" operation is performed to adjust the calibration curve. If a graphite tube failed before the completion of 160 burns the test plan called for the analysis of a new set of 160 samples with a new graphite tube. Also, under the test plan, all the synthesized samples (calibration and verification samples), a few of the correlation samples, and the random samples are to be analyzed on the A/E35U-3 (henceforth Dash-3) atomic emission spectrometer which is the primary spectrometer of the SOAP program. This last requirement is to provide a basis for assessing the suitability of the PWMA for the SOAP program by a comparison of the results from the PWMA with those from Dash-3. Another hoped for benefit of analyzing the samples on the Dash-3 spectrometer is to determine a means of translating the well established decision rules (rules for deciding when the results of an oil analysis indicate that the performance of the aircraft engine is to be considered normal, marginal or abnormal) into equivalent decision rules for the PWMA; this is to be done by estimating the functional relationship between the corresponding measurement on A/E35U-3 and the PWMA.

Due to time constraints, breakdowns of the PWMA, and other operational considerations the field test could not be completed as planned at all bases; the number of tubes tested was different for the four test sites. There were also differences between the bases in the way the test data was collected. For example, at one base the PWMA was calibrated every day instead of every other day. At another base when a graphite tube failed before the completion of 160 burn sequence, the tube was replaced and the burn sequence was continued instead of initiating a new sequence of 160 burns. There were also a few minor differences in the way the oil samples were analyzed such as not shaking the oil bottle thoroughly before drawing a sample and analyzing 80 samples in one day instead of over two days as required by the plan.

We performed several different statistical analyses to measure the accuracy and repeatability of the PWMA in analyzing oil samples. It should be pointed out that in performing these analyses we have tried to ascertain if significant statistical differences exist between the oil analysis results for the instruments (the four PWMA's), between different graphite tubes for the same instrument, and between days (measurements for the same oil sample on different days for a fixed instrument/graphite tube combination). However, statistical significance may or may not imply operational significance i.e., unsuitability for SOAP. In other words, it is conceivable that there be significant statistical differences between the instruments and yet meet the requirements for SOAP. Also, as will be discussed in more detail later, it may be possible to reduce or eliminate some of the observed statistical differences by changes in the operating procedures and/or minor design changes. Note also that all of the analyses reported here were performed on the measurements for synthesized samples (calibration and verification samples) and/or correlation samples; the reason being that these samples were analyzed by all instruments, for all tubes on each day and also on the Dash-3 spectrometer.

## 2.2 RESULTS AND CONCLUSIONS

Nine correlation samples (mixtures of used and synthesized oil) supplied by JOAP-TSC were analyzed on the four PWMA's and with each of the graphite tubes tested. We performed analyses of variance on the data to check for statistically significant (at the one percent level) differences between the instruments and/or between different graphite tubes. The results are in Tables 2.1 - 2.9; an asterisk in the last column indicates statistical significance for the corresponding source of variability. In almost all cases, statistically significant differences between the instruments as well as between different graphite tubes were observed.

The same type of statistical procedures were applied to the data from the verification samples (synthesized samples with predetermined concentration levels) with similar results viz., significant differences between the PWMA's and also the graphite tubes. Further, since these verification samples were burnt twice (early and late) on alternate days, we did an analysis of variance to test for a significant day to day effect and also for a time of day effect; the latter would indicate a calibration drift as a day progresses. The tests revealed both effects to be statistically significant (Table 2.10).

The data for the correlation and verification samples from the Dash-3 spectrometer was similarly analyzed and in several cases significant differences between the four Dash-3 instruments and a significant day to day effect was noted; see Tables 2.11 - 2.19 and 2.20.

In order to establish a basis for a direct comparison of the PWMA with the Dash-3 spectrometer which is the "standard" instrument for SOAP, for each of the nine correlation samples we plotted the mean of all the measurements from Dash-3 against the corresponding mean for the PWMA, one plot for each wear metal (Figures 2.1 - 2.3). These graphs exhibit a good linear relationship between the two data sets, indicating a "compatibility" between the PWMA and the Dash-3. A more extensive investigation will be necessary to accurately establish this relationship. The straight line representation may then be used to transform the existing Dash-3 "decision tables" (for diagnostic monitoring of equipment) into equivalent decision tables for the PWMA, if it were to be adopted for SOAP.

Plots of the overall standard deviations for the PWMA and the Dash-3, (computed from all the available data for the nine correlation samples) are presented in Figures 2.4 - 2.6. The half-length of each horizontal bar is equal to the Dash-3 standard deviation and the half-length of a vertical bar measures the PWMA standard deviation. In most cases, there are nine crossbars on each graph, one for each of the nine correlation samples. In some graphs fewer crossbars are presented because some of the standard deviations were small. It can be seen from these graphs that the uncertainties, as measured by the overall standard deviations, are comparable for the PWMA and the Dash-3 spectrometer. It should be noted that the PWMA standard deviations were based on about five times as many observations as those for the Dash-3. Also, the Dash-3 standard deviations include the day to day variability component since repeated burns for the same sample were made on different days whereas with the PWMA all repeated burns were completed on the same day.

The PWMA's calibration algorithm that converts the light absorbance values into concentration levels uses three points to fit a rational polynomial calibration curve. For one of the graphite tubes used at Langley AFB, we extracted the actual absorbance values for the three calibration samples and the three verification samples and examined the functional relationship between the absorbance and the concentration. For this limited data, we observed the following: (1) the functional relationship was different for different days for the same sample, indicating a need for daily calibration and (2) increasing the number of calibration points (we tried six) and the choice of a more appropriate calibration curve (we tried an exponential curve) can result in reducing the variability in the data from the PWMA. Details are in [1].

In conclusion, the analysis of the data from the PWMA field test revealed statistically significant differences between the instruments and also between graphite tubes for a fixed instrument. A significant day to day effect as well as a time of day effect was also evident. However, statistically significant differences between the PWMA's does not necessarily imply its unsuitability for SOAP. The determination of the acceptability of the PWMA should be based on realistic accuracy and repeatability criteria desirable for SOAP, the need for a portable oil analyzer, maintainability requirements and of course various cost considerations. It is of interest to note that the measurements from the Dash-3 spectrometer, which is the primary instrument for oil analysis, also exhibited significant differences between the instruments, as well as a day to day effect. Another point to remember is that the data collection process was not uniform at the four test sites. As indicated earlier, at some sites the PWMA was calibrated every day and at other sites the instrument was calibrated every other day. The requirement for the initiation of a new 160 burn test sequence each time a graphite tube was replaced, was not adhered to at all bases. There were also differences in the sample selection/injection process. At a debriefing after the conclusion of the field test, it was noted that sample injection gun's trigger can accidentally get squeezed more than once, resulting in a splattering of the sample in and around the graphite tube and this can result in incorrect measurements. All these factors may have had some bearing on the observed differences in the data from the PWMA. It would appear that a combination of a close adherence to the prescribed operating procedures, minor design changes and an improved calibration scheme would improve the PWMA performance.

Analyses of Variance Correlation Sample Data for FWMA
For Element: FE

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 138.62 | 46.21 | 60.4* |
| Tubes/Instrs | 22 | 311.90 | 14.18 | 18.5* |
| Residual | 104 | 79.60 | .77 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 1917.66 | 639.22 | 156.6* |
| Tubes/Instrs | 22 | 1109.91 | 50.45 | 12.4* |
| Residual | 104 | 424.40 | 4.08 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 406.76 | 135.59 | 38.4* |
| Tubes/Instrs | 22 | 492.41 | 22.38 | 6.3* |
| Residual | 104 | 366.80 | 3.53 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 219.16 | 73.05 | 63.9* |
| Tubes/Instrs | 21 | 176.25 | 8.39 | 7.3* |
| Residual | 100 | 114.40 | 1.14 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 662.14 | 220.71 | 34.3* |
| Tubes/Instrs | 21 | 1364.39 | 64.97 | 10.1* |
| Residual | 100 | 644.00 | 6.44 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 14.92 | 4.97 | 10.8* |
| Tubes/Instrs | 21 | 123.69 | 5.89 | 12.8* |
| Residual | 100 | 46.00 | .46 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 23461.52 | 7820.51 | 106.1* |
| Tubes/Instrs | 20 | 8892.48 | 444.62 | 6.0* |
| Residual | 96 | 7079.20 | 73.74 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 152.68 | 50.89 | 18.8* |
| Tubes/Instrs | 17 | 220.88 | 12.99 | 4.8* |
| Residual | 84 | 227.20 | 2.70 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 2171.11 | 723.70 | 134.5* |
| Tubes/Instrs | 17 | 9227.12 | 542.77 | 100.9* |
| Residual | 84 | 452.00 | 5.38 | |

Table 2.1

Analyses of Variance Correlation Sample Data for FWMA
For Element: AG

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 152.94 | 50.98 | 98.9* |
| Tubes/Instrs | 22 | 283.99 | 12.91 | 25.0* |
| Residual | 104 | 53.60 | .52 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 130.36 | 43.45 | 56.8* |
| Tubes/Instrs | 22 | 158.27 | 7.19 | 9.4* |
| Residual | 104 | 79.60 | .77 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 94.46 | 31.49 | 15.0* |
| Tubes/Instrs | 22 | 318.04 | 14.46 | 6.9* |
| Residual | 104 | 218.40 | 2.10 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 469.67 | 156.56 | 240.1* |
| Tubes/Instrs | 21 | 425.50 | 20.26 | 31.1* |
| Residual | 100 | 65.20 | .65 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 137.65 | 45.88 | 254.9* |
| Tubes/Instrs | 21 | 201.55 | 9.60 | 53.3* |
| Residual | 100 | 18.00 | .18 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 28.79 | 9.60 | 10.1* |
| Tubes/Instrs | 21 | 114.78 | 5.47 | 5.8* |
| Residual | 100 | 94.80 | .95 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | .05 | .02 | .5 |
| Tubes/Instrs | 20 | .72 | .04 | 1.1 |
| Residual | 96 | 3.20 | .03 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | .00 | .00 | 1.0 |
| Tubes/Instrs | 17 | .00 | .00 | 1.0 |
| Residual | 84 | .00 | .00 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | .00 | .00 | 1.0 |
| Tubes/Instrs | 17 | .00 | .00 | 1.0 |
| Residual | 84 | .00 | .00 | |

Table 2.2

Analyses of Variance Correlation Sample Data for FWMA
For Element: AL

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 716.19 | 238.73 | 11.4* |
| Tubes/Instrs | 22 | 2182.31 | 99.20 | 4.7* |
| Residual | 104 | 2180.00 | 20.96 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 485.14 | 161.71 | 9.9* |
| Tubes/Instrs | 22 | 600.59 | 27.30 | 1.7 |
| Residual | 104 | 1694.80 | 16.30 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 442.89 | 147.63 | 17.4* |
| Tubes/Instrs | 21 | 698.99 | 33.29 | 3.9* |
| Residual | 100 | 848.40 | 8.48 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 683.21 | 227.74 | 21.3* |
| Tubes/Instrs | 21 | 782.35 | 37.25 | 3.5* |
| Residual | 100 | 1067.20 | 10.67 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 69.78 | 23.26 | 3.3 |
| Tubes/Instrs | 21 | 415.45 | 19.78 | 2.8* |
| Residual | 100 | 714.80 | 7.15 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 45.45 | 15.15 | .7 |
| Tubes/Instrs | 21 | 1243.07 | 59.19 | 2.8* |
| Residual | 100 | 2126.80 | 21.27 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 2662.31 | 887.44 | 43.4* |
| Tubes/Instrs | 20 | 2253.79 | 112.69 | 5.5* |
| Residual | 96 | 1961.60 | 20.43 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 1069.23 | 356.41 | 14.9* |
| Tubes/Instrs | 16 | 2801.01 | 175.06 | 7.3* |
| Residual | 80 | 1912.40 | 23.90 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 877.43 | 292.48 | 14.1* |
| Tubes/Instrs | 16 | 988.76 | 61.80 | 3.0* |
| Residual | 80 | 1663.60 | 20.79 | |

Table 2.3

Analyses of Variance Correlation Sample Data for FWMA
For Element: CR

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 83.83 | 27.94 | 27.4* |
| Tubes/Instrs | 22 | 123.40 | 5.61 | 5.5* |
| Residual | 104 | 106.00 | 1.02 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 152.30 | 50.77 | 54.8* |
| Tubes/Instrs | 22 | 136.81 | 6.22 | 6.7* |
| Residual | 104 | 96.40 | .93 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 23.98 | 7.99 | 77.0* |
| Tubes/Instrs | 22 | 15.69 | .71 | 6.9* |
| Residual | 104 | 10.80 | .10 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 595.23 | 198.41 | 384.5* |
| Tubes/Instrs | 21 | 139.45 | 6.64 | 12.9* |
| Residual | 100 | 51.60 | .52 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 72.43 | 24.14 | 49.5* |
| Tubes/Instrs | 21 | 130.48 | 6.21 | 12.7* |
| Residual | 100 | 48.80 | .49 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 24.44 | 8.15 | 6.7* |
| Tubes/Instrs | 21 | 43.05 | 2.05 | 1.7 |
| Residual | 100 | 121.20 | 1.21 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 18.42 | 6.14 | 44.7* |
| Tubes/Instrs | 20 | 21.18 | 1.06 | 7.7* |
| Residual | 96 | 13.20 | .14 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 30.89 | 10.30 | 63.6* |
| Tubes/Instrs | 17 | 18.50 | 1.09 | 6.7* |
| Residual | 84 | 13.60 | .16 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 15.43 | 5.14 | 51.4* |
| Tubes/Instrs | 17 | 26.80 | 1.58 | 15.8* |
| Residual | 84 | 8.40 | .10 | |

Table 2.4

Analyses of Variance Correlation Sample Data for FWMA
For Element: CU

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 1259.86 | 419.95 | 49.4* |
| Tubes/Instrs | 21 | 3595.37 | 171.21 | 20.1* |
| Residual | 100 | 850.00 | 8.50 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 167.08 | 55.69 | 71.3* |
| Tubes/Instrs | 22 | 183.15 | 8.32 | 10.7* |
| Residual | 104 | 81.20 | .78 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 2539.80 | 846.60 | 29.7* |
| Tubes/Instrs | 22 | 6672.50 | 303.30 | 10.6* |
| Residual | 104 | 2968.00 | 28.54 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 330.01 | 110.00 | 53.4* |
| Tubes/Instrs | 21 | 224.75 | 10.70 | 5.2* |
| Residual | 100 | 206.00 | 2.06 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 69.76 | 23.25 | .9 |
| Tubes/Instrs | 21 | 398.35 | 18.97 | .7 |
| Residual | 100 | 2618.80 | 26.19 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 65.40 | 21.80 | 8.1* |
| Tubes/Instrs | 21 | 199.40 | 9.50 | 3.5* |
| Residual | 100 | 269.20 | 2.69 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 4821.14 | 1607.05 | 44.4* |
| Tubes/Instrs | 20 | 3078.65 | 153.93 | 4.3* |
| Residual | 96 | 3471.20 | 36.16 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 4314.87 | 1438.29 | 92.6* |
| Tubes/Instrs | 16 | 3703.24 | 231.45 | 14.9* |
| Residual | 80 | 1243.20 | 15.54 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 3482.35 | 1160.78 | 184.4* |
| Tubes/Instrs | 17 | 13006.99 | 765.12 | 121.5* |
| Residual | 84 | 528.80 | 6.30 | |

Table 2.5

Analyses of Variance Correlation Sample Data for FWMA
For Element: MG

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 114.76 | 38.25 | 42.3* |
| Tubes/Instrs | 22 | 136.81 | 6.22 | 6.9* |
| Residual | 104 | 94.00 | .90 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 1324.92 | 441.64 | 92.8* |
| Tubes/Instrs | 22 | 334.81 | 15.22 | 3.2* |
| Residual | 104 | 495.20 | 4.76 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 494.26 | 164.75 | 16.6* |
| Tubes/Instrs | 22 | 1226.36 | 55.74 | 5.6* |
| Residual | 104 | 1032.80 | 9.93 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 1333.83 | 444.61 | 90.1* |
| Tubes/Instrs | 21 | 220.45 | 10.50 | 2.1* |
| Residual | 100 | 493.20 | 4.93 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 494.89 | 164.96 | 103.6* |
| Tubes/Instrs | 21 | 1279.07 | 60.91 | 38.3* |
| Residual | 100 | 159.20 | 1.59 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 7.01 | 2.34 | 7.0* |
| Tubes/Instrs | 21 | 20.59 | .98 | 3.0* |
| Residual | 100 | 33.20 | .33 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 1490.04 | 496.68 | 71.0* |
| Tubes/Instrs | 20 | 898.55 | 44.93 | 6.4* |
| Residual | 96 | 672.00 | 7.00 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 242.27 | 80.76 | 20.4* |
| Tubes/Instrs | 17 | 2264.59 | 133.21 | 33.6* |
| Residual | 84 | 333.20 | 3.97 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 79.33 | 26.44 | 17.6* |
| Tubes/Instrs | 17 | 654.12 | 38.48 | 25.6* |
| Residual | 84 | 126.40 | 1.50 | |

Table 2.6

Analyses of Variance Correlation Sample Data for PWMA
For Element: NI

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 86.50 | 28.83 | 187.4* |
| Tubes/Instrs | 22 | 70.60 | 3.21 | 20.9* |
| Residual | 104 | 16.00 | .15 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 269.89 | 89.96 | 168.3* |
| Tubes/Instrs | 22 | 181.71 | 8.26 | 15.4* |
| Residual | 104 | 55.60 | .53 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 1498.20 | 499.40 | 88.4* |
| Tubes/Instrs | 22 | 957.77 | 43.53 | 7.7* |
| Residual | 104 | 587.60 | 5.65 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 266.67 | 88.89 | 300.3* |
| Tubes/Instrs | 21 | 125.29 | 5.97 | 20.2* |
| Residual | 100 | 29.60 | .30 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 13.39 | 4.46 | 123.9* |
| Tubes/Instrs | 21 | 30.65 | 1.46 | 40.5* |
| Residual | 100 | 3.60 | .04 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 88.46 | 29.49 | 37.6* |
| Tubes/Instrs | 21 | 134.93 | 6.43 | 8.2* |
| Residual | 100 | 78.40 | .78 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 762.48 | 254.16 | 209.6* |
| Tubes/Instrs | 20 | 73.92 | 3.70 | 3.0* |
| Residual | 96 | 116.40 | 1.21 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 52.34 | 17.45 | 18.2* |
| Tubes/Instrs | 17 | 88.82 | 5.22 | 5.5* |
| Residual | 84 | 80.40 | .96 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 86.44 | 28.81 | 106.2* |
| Tubes/Instrs | 17 | 586.72 | 34.51 | 127.2* |
| Residual | 84 | 22.80 | .27 | |

Table 2.7

Analyses of Variance Correlation Sample Data for FWMA
For Element: SI

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 20.53 | 6.84 | .4 |
| Tubes/Instrs | 21 | 362.30 | 17.25 | 1.0 |
| Residual | 100 | 1749.20 | 17.49 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 23.96 | 7.99 | 1.4 |
| Tubes/Instrs | 22 | 128.24 | 5.83 | 1.0 |
| Residual | 104 | 608.80 | 5.85 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 478.08 | 159.36 | .7 |
| Tubes/Instrs | 22 | 22211.65 | 1009.62 | 4.1* |
| Residual | 104 | 25335.20 | 243.61 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 38.27 | 12.76 | 1.6 |
| Tubes/Instrs | 21 | 175.22 | 8.34 | 1.0 |
| Residual | 100 | 803.60 | 8.04 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 81.52 | 27.17 | 2.1 |
| Tubes/Instrs | 21 | 302.83 | 14.42 | 1.1 |
| Residual | 100 | 1311.60 | 13.12 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 146.62 | 48.87 | 3.3 |
| Tubes/Instrs | 20 | 476.50 | 23.83 | 1.6 |
| Residual | 96 | 1413.20 | 14.72 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 1136.21 | 378.74 | 20.9* |
| Tubes/Instrs | 19 | 3132.44 | 164.87 | 9.1* |
| Residual | 92 | 1666.40 | 18.11 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 1550.80 | 516.93 | 2.3 |
| Tubes/Instrs | 17 | 2704.77 | 159.10 | .7 |
| Residual | 84 | 19151.20 | 227.99 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 281.68 | 93.89 | 25.9* |
| Tubes/Instrs | 17 | 2145.71 | 126.22 | 34.9* |
| Residual | 84 | 304.00 | 3.62 | |

Table 2.8

Analyses of Variance Correlation Sample Data for PWMA
For Element: TI

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 77.00 | 25.67 | 63.0* |
| Tubes/Instrs | 22 | 99.68 | 4.53 | 11.1* |
| Residual | 104 | 42.40 | .41 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 91.34 | 30.45 | 19.4* |
| Tubes/Instrs | 22 | 73.59 | 3.35 | 2.1* |
| Residual | 104 | 163.60 | 1.57 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 371.61 | 123.87 | 15.2* |
| Tubes/Instrs | 22 | 964.49 | 43.84 | 5.4* |
| Residual | 104 | 849.60 | 8.17 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 327.48 | 109.16 | 45.3* |
| Tubes/Instrs | 21 | 180.52 | 8.60 | 3.6* |
| Residual | 100 | 240.80 | 2.41 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 265.62 | 88.54 | 76.6* |
| Tubes/Instrs | 21 | 425.61 | 20.27 | 17.5* |
| Residual | 100 | 115.60 | 1.16 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 53.01 | 17.67 | 18.4* |
| Tubes/Instrs | 21 | 175.12 | 8.34 | 8.7* |
| Residual | 100 | 96.00 | .96 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 537.56 | 179.19 | 58.0* |
| Tubes/Instrs | 20 | 156.83 | 7.84 | 2.5* |
| Residual | 96 | 296.40 | 3.09 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 46.78 | 15.59 | 9.9* |
| Tubes/Instrs | 17 | 92.21 | 5.42 | 3.4* |
| Residual | 84 | 132.40 | 1.58 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 13.45 | 4.48 | 24.1* |
| Tubes/Instrs | 17 | 14.80 | .87 | 4.7* |
| Residual | 84 | 15.60 | .19 | |

Table 2.9

Verification Sample Data for FWMA
Analyses of Variance

For Element **Fe**

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 2220.223 | 370.037 | 14.52* |
| Tubes/Inst | 50 | 5607.089 | 112.142 | 4.40* |
| Days/Tubes | 126 | 9143.548 | 72.568 | 2.85* |
| Early-Late | 146 | 8874.806 | 60.786 | 2.38* |
| Residual | 165 | 4205.667 | 25.489 | |

For Element **Ag**

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 41.472 | 6.912 | 15.24* |
| Tubes/Inst | 50 | 146.576 | 2.932 | 6.46* |
| Days/Tubes | 126 | 101.310 | .804 | 1.77* |
| Early-Late | 146 | 96.597 | .662 | 1.46* |
| Residual | 165 | 74.833 | .454 | |

For Element **Al**

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 800.830 | 133.472 | 11.80* |
| Tubes/Inst | 50 | 1226.932 | 24.539 | 2.17* |
| Days/Tubes | 126 | 2795.636 | 22.188 | 1.96* |
| Early-Late | 146 | 2176.667 | 14.909 | 1.32 |
| Residual | 165 | 1866.000 | 11.309 | |

For Element **Cr**

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 14.163 | 2.361 | 9.09* |
| Tubes/Inst | 50 | 53.855 | 1.077 | 4.15* |
| Days/Tubes | 126 | 112.849 | .896 | 3.45* |
| Early-Late | 146 | 71.278 | .488 | 1.88* |
| Residual | 165 | 42.833 | .260 | |

For Element **Cu**

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 48.728 | 8.121 | 2.15 |
| Tubes/Inst | 50 | 1354.869 | 27.097 | 7.16* |
| Days/Tubes | 126 | 1654.450 | 13.131 | 3.47* |
| Early-Late | 146 | 1667.375 | 11.420 | 3.02* |
| Residual | 165 | 624.667 | 3.786 | |

For Element **Mg**

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 1384.444 | 230.741 | 76.27* |
| Tubes/Inst | 50 | 513.515 | 10.270 | 3.39* |
| Days/Tubes | 126 | 1390.036 | 11.032 | 3.65* |
| Early-Late | 146 | 1063.833 | 7.287 | 2.41* |
| Residual | 165 | 499.167 | 3.025 | |

Table 2.10

Verification Sample Data for PWMA
Analyses of Variance

For Element **Ni**

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 65.918 | 10.986 | 11.98* |
| Tubes/Inst | 50 | 368.164 | 7.363 | 8.03* |
| Days/Tubes | 126 | 532.298 | 4.225 | 4.61* |
| Early-Late | 146 | 503.903 | 3.451 | 3.76* |
| Residual | 165 | 151.333 | .917 | |

For Element **Si**

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 366.739 | 61.123 | 5.17* |
| Tubes/Inst | 50 | 1923.603 | 38.472 | 3.25* |
| Days/Tubes | 126 | 3548.854 | 28.166 | 2.38* |
| Early-Late | 146 | 2905.486 | 19.901 | 1.68* |
| Residual | 165 | 1951.500 | 11.827 | |

For Element **Ti**

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 55.148 | 9.191 | 8.97* |
| Tubes/Inst | 50 | 236.185 | 4.724 | 4.61* |
| Days/Tubes | 126 | 529.649 | 4.204 | 4.10* |
| Early-Late | 146 | 402.653 | 2.758 | 2.69* |
| Residual | 165 | 169.000 | 1.024 | |

Table 2.10

Analyses of Variance Correlation Sample Data for Dash-3
For Element: FE

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 32.95 | 10.98 | 8.1* |
| Residual | 22 | 29.67 | 1.35 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 580.81 | 193.60 | 3.8 |
| Residual | 22 | 1114.73 | 50.67 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 94.17 | 31.39 | 8.9* |
| Residual | 24 | 84.55 | 3.52 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 12.84 | 4.28 | 2.5 |
| Residual | 18 | 31.02 | 1.72 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 328.41 | 109.47 | 10.1* |
| Residual | 18 | 194.55 | 10.81 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 8.41 | 2.80 | 4.4 |
| Residual | 21 | 13.43 | .64 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 1557.02 | 519.01 | 5.2* |
| Residual | 22 | 2216.52 | 100.75 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 140.55 | 46.85 | 17.8* |
| Residual | 16 | 42.00 | 2.62 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 1062.97 | 354.32 | 14.5* |
| Residual | 16 | 390.83 | 24.43 | |

Table 2.11

Analyses of Variance Correlation Sample Data for Dash-3
For Element: AG

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 34.19 | 11.40 | 17.6* |
| Residual | 22 | 14.27 | .65 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 215.91 | 71.97 | 12.1* |
| Residual | 22 | 130.43 | 5.93 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 145.52 | 48.51 | 6.0* |
| Residual | 24 | 193.45 | 8.06 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 36.34 | 12.11 | 17.5* |
| Residual | 18 | 12.43 | .69 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 18.18 | 6.06 | 2.8 |
| Residual | 18 | 39.10 | 2.17 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 44.01 | 14.67 | 12.1* |
| Residual | 21 | 25.43 | 1.21 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 3.28 | 1.09 | 7.2* |
| Residual | 22 | 3.33 | .15 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 2.55 | .85 | NO |
| Residual | 16 | .00 | .00 | TEST |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 2.55 | .85 | NO |
| Residual | 16 | .00 | .00 | TEST |

Table 2.12

Analyses of Variance Correlation Sample Data for Dash-3
For Element: AL

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 95.48 | 31.83 | 5.3* |
| Residual | 22 | 131.48 | 5.98 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 53.60 | 17.87 | .6 |
| Residual | 22 | 696.40 | 31.65 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 100.31 | 33.44 | 11.4* |
| Residual | 24 | 70.55 | 2.94 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 59.10 | 19.70 | 4.4 |
| Residual | 18 | 80.76 | 4.49 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 41.62 | 13.87 | 7.0* |
| Residual | 18 | 35.88 | 1.99 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 143.76 | 47.92 | 13.1* |
| Residual | 21 | 76.88 | 3.66 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 158.17 | 52.72 | 2.7 |
| Residual | 22 | 428.48 | 19.48 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 220.16 | 73.39 | 2.3 |
| Residual | 16 | 503.04 | 31.44 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 129.83 | 43.28 | 5.7* |
| Residual | 16 | 122.37 | 7.65 | |

Table 2.13

Analyses of Variance Correlation Sample Data for Dash-3
For Element: CR

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 2.47 | .82 | 1.9 |
| Residual | 22 | 9.57 | .43 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 8.33 | 2.78 | 6.3* |
| Residual | 22 | 9.67 | .44 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 7.73 | 2.58 | 12.5* |
| Residual | 24 | 4.95 | .21 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 3.27 | 1.09 | 1.6 |
| Residual | 18 | 12.05 | .67 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 8.03 | 2.68 | 5.1* |
| Residual | 18 | 9.43 | .52 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | .29 | .10 | .1 |
| Residual | 21 | 16.35 | .78 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 1.37 | .46 | 3.1 |
| Residual | 22 | 3.25 | .15 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 2.34 | .78 | 1.0 |
| Residual | 16 | 12.21 | .76 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 11.01 | 3.67 | 38.1* |
| Residual | 16 | 1.54 | .10 | |

Table 2.14

Analyses of Variance Correlation Sample Data for Dash-3
For Element: CU

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 73.87 | 24.62 | 1.6 |
| Residual | 22 | 338.02 | 15.36 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 58.28 | 19.43 | .4 |
| Residual | 22 | 1142.83 | 51.95 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 440.79 | 146.93 | 3.0 |
| Residual | 24 | 1170.93 | 48.79 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | .40 | .13 | .1 |
| Residual | 18 | 26.19 | 1.46 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 4.53 | 1.51 | 3.9 |
| Residual | 18 | 6.93 | .38 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 4.31 | 1.44 | 1.7 |
| Residual | 21 | 17.93 | .85 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 19.32 | 6.44 | .4 |
| Residual | 22 | 342.57 | 15.57 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 808.80 | 269.60 | 26.0* |
| Residual | 16 | 166.00 | 10.37 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 741.58 | 247.19 | 45.9* |
| Residual | 16 | 86.17 | 5.39 | |

Table 2.15

Analyses of Variance Correlation Sample Data for Dash-3
For Element: MG

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 42.82 | 14.27 | 22.7* |
| Residual | 22 | 13.83 | .63 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 84.58 | 28.19 | 9.8* |
| Residual | 22 | 63.27 | 2.88 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 230.28 | 76.76 | 5.7* |
| Residual | 24 | 325.15 | 13.55 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 43.08 | 14.36 | 1.9 |
| Residual | 18 | 135.69 | 7.54 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 248.58 | 82.86 | 2.8 |
| Residual | 18 | 528.19 | 29.34 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 2.48 | .83 | 1.2 |
| Residual | 21 | 14.88 | .71 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 244.75 | 81.58 | 1.9 |
| Residual | 22 | 933.90 | 42.45 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 997.41 | 332.47 | 2.0 |
| Residual | 16 | 2677.54 | 167.35 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 301.28 | 100.43 | 3.1 |
| Residual | 16 | 521.67 | 32.60 | |

Table 2.16

Analyses of Variance Correlation Sample Data for Dash-3
For Element: NI

| Source | DF | Correlation Sample 1 Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 5.91 | 1.97 | 1.3 |
| Residual | 22 | 32.43 | 1.47 | |

| Source | DF | Correlation Sample 2 Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 25.55 | 8.52 | 2.6 |
| Residual | 22 | 71.07 | 3.23 | |

| Source | DF | Correlation Sample 3 Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 152.74 | 50.91 | 1.9 |
| Residual | 24 | 660.11 | 27.50 | |

| Source | DF | Correlation Sample 4 Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 3.88 | 1.29 | 1.8 |
| Residual | 18 | 12.71 | .71 | |

| Source | DF | Correlation Sample 5 Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 4.90 | 1.63 | 8.0* |
| Residual | 18 | 3.69 | .21 | |

| Source | DF | Correlation Sample 6 Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 198.69 | 66.23 | 3.1 |
| Residual | 21 | 450.35 | 21.45 | |

| Source | DF | Correlation Sample 7 Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 18.63 | 6.21 | 4.0 |
| Residual | 22 | 33.98 | 1.54 | |

| Source | DF | Correlation Sample 8 Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 6.93 | 2.31 | 4.2 |
| Residual | 16 | 8.87 | .55 | |

| Source | DF | Correlation Sample 9 Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 72.74 | 24.25 | 23.9* |
| Residual | 16 | 16.21 | 1.01 | |

Table 2.17

Analyses of Variance Correlation Sample Data for Dash-3
For Element: SI

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 23.45 | 7.82 | 1.4 |
| Residual | 22 | 124.40 | 5.65 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 3.55 | 1.18 | .3 |
| Residual | 22 | 79.57 | 3.62 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 54.41 | 18.14 | 2.5 |
| Residual | 24 | 171.30 | 7.14 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 64.10 | 21.37 | 9.2* |
| Residual | 18 | 41.71 | 2.32 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 43.46 | 14.49 | .3 |
| Residual | 18 | 851.86 | 47.33 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 9.03 | 3.01 | .6 |
| Residual | 21 | 109.93 | 5.23 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 494.53 | 164.84 | 4.0 |
| Residual | 22 | 905.93 | 41.18 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 52.38 | 17.46 | 1.7 |
| Residual | 16 | 164.17 | 10.26 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 81.33 | 27.11 | 2.0 |
| Residual | 16 | 214.87 | 13.43 | |

Table 2.18

Analyses of Variance Correlation Sample Data for Dash-3
For Element: TI

Correlation Sample 1

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 20.86 | 6.95 | 2.7 |
| Residual | 22 | 57.48 | 2.61 | |

Correlation Sample 2

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 1.42 | .47 | .1 |
| Residual | 22 | 85.23 | 3.87 | |

Correlation Sample 3

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 86.86 | 28.95 | 10.9* |
| Residual | 24 | 64.00 | 2.67 | |

Correlation Sample 4

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 13.26 | 4.42 | 1.5 |
| Residual | 18 | 53.69 | 2.98 | |

Correlation Sample 5

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 36.03 | 12.01 | 3.5 |
| Residual | 18 | 62.33 | 3.46 | |

Correlation Sample 6

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 19.18 | 6.39 | 2.1 |
| Residual | 21 | 65.38 | 3.11 | |

Correlation Sample 7

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 10.40 | 3.47 | 1.0 |
| Residual | 22 | 74.10 | 3.37 | |

Correlation Sample 8

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 66.92 | 22.31 | 13.3* |
| Residual | 16 | 26.83 | 1.68 | |

Correlation Sample 9

| Source | DF | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Instruments | 3 | 13.58 | 4.53 | 4.2 |
| Residual | 16 | 17.37 | 1.09 | |

Table 2.19

Table 2.20Verification Sample Data for DASH-3
Analyses of Variance

For Element **Fe**

| SOURCE | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 2006.276 | 334.379 | 16.30* |
| Days/Insts | 128 | 7055.687 | 55.123 | 2.69* |
| Residual | 68 | 1394.833 | 20.512 | |

For Element **Ag**

| SOURCE | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 101.762 | 16.960 | 66.54* |
| Days/Insts | 128 | 129.479 | 1.012 | 3.97* |
| Residual | 68 | 17.333 | .255 | |

For Element **Al**

| SOURCE | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 532.079 | 88.680 | 16.95* |
| Days/Insts | 128 | 790.073 | 6.172 | 1.18 |
| Residual | 68 | 355.667 | 5.230 | |

For Element **Cr**

| SOURCE | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 54.457 | 9.076 | 4.40* |
| Days/Insts | 128 | 642.357 | 5.018 | 2.43* |
| Residual | 68 | 140.333 | 2.064 | |

For Element **Cu**

| SOURCE | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 155.180 | 25.863 | 14.60* |
| Days/Insts | 128 | 1324.410 | 10.347 | 5.84* |
| Residual | 68 | 120.500 | 1.772 | |

For Element **Mg**

| SOURCE | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 233.224 | 38.871 | 13.84* |
| Days/Insts | 128 | 1134.536 | 8.864 | 3.16* |
| Residual | 68 | 191.000 | 2.809 | |

For Element **Ni**

| SOURCE | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 21.907 | 3.651 | 2.54 |
| Days/Insts | 128 | 523.193 | 4.087 | 2.84* |
| Residual | 68 | 97.833 | 1.439 | |

For Element **Si**

| SOURCE | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 432.623 | 72.104 | 18.70* |
| Days/Insts | 128 | 1927.791 | 15.061 | 3.91* |
| Residual | 68 | 262.167 | 3.855 | |

For Element **Ti**

| SOURCE | DF | SS | MS | F |
|---|---|---|---|---|
| Instrument | 6 | 284.599 | 47.433 | 5.62* |
| Days/Insts | 128 | 3200.104 | 25.001 | 2.96* |
| Residual | 68 | 573.833 | 8.439 | |

Figure 2.1 Correlation Samples

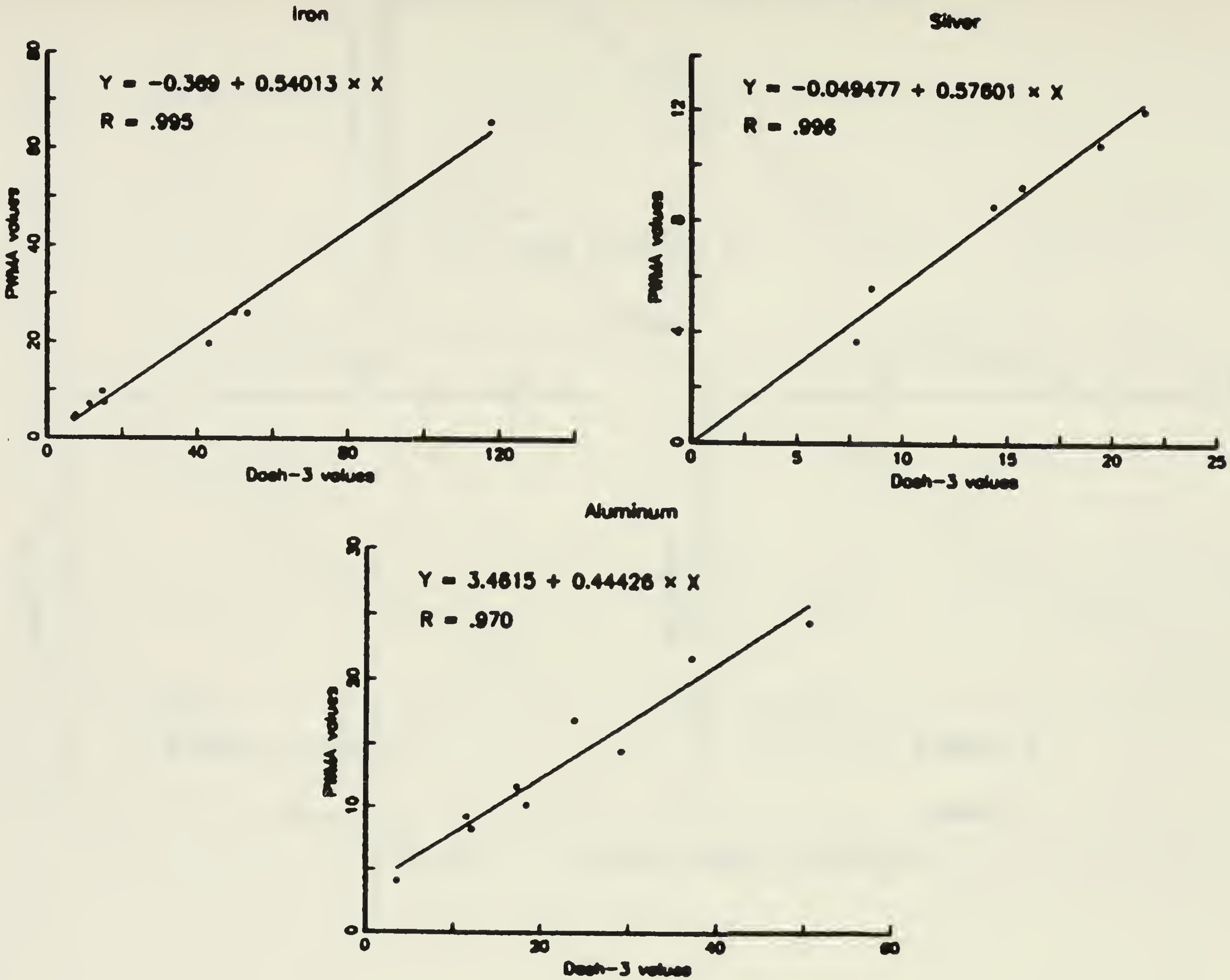
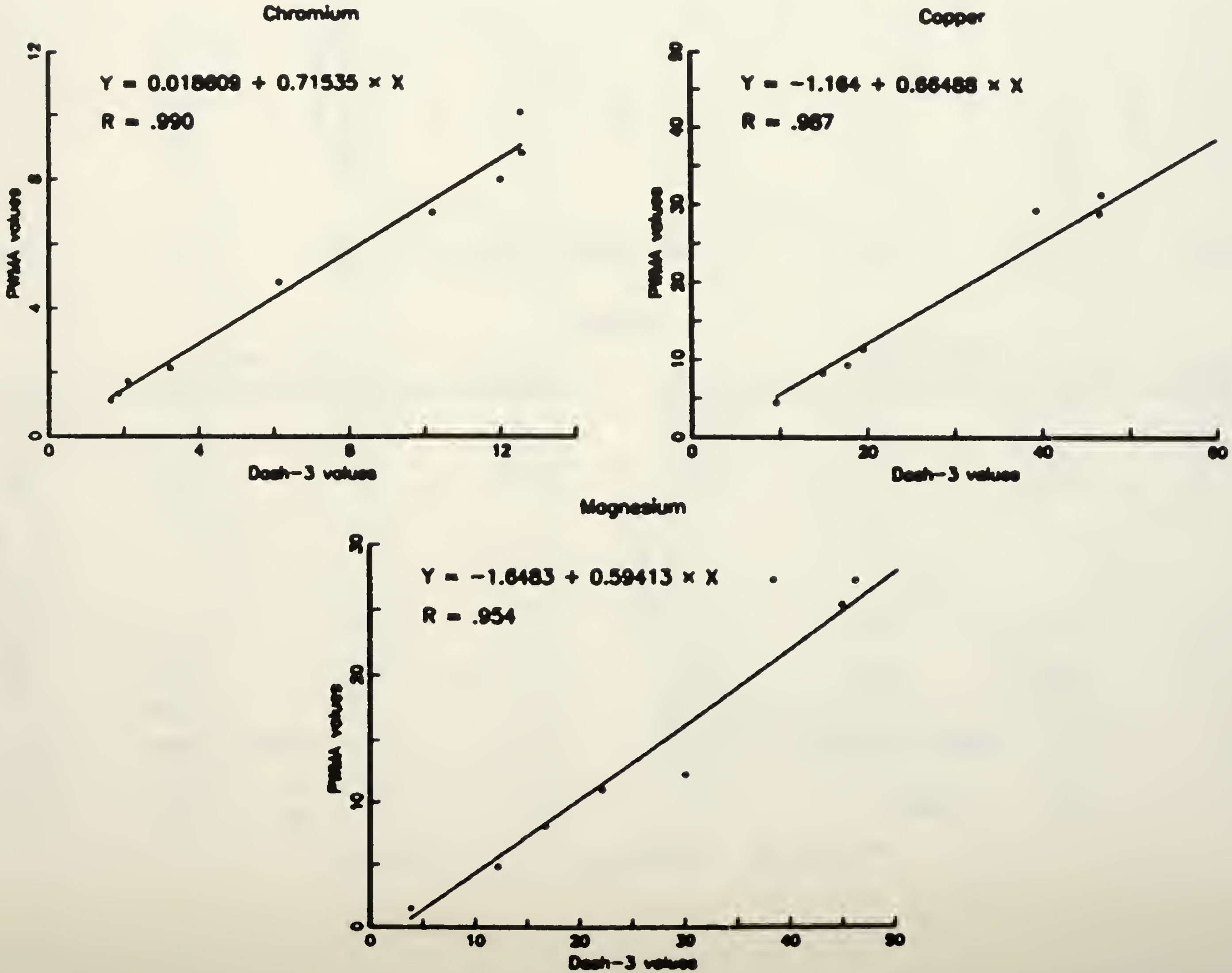


Figure 2.2 Correlation Samples



# Figure 2.3 Correlation Samples

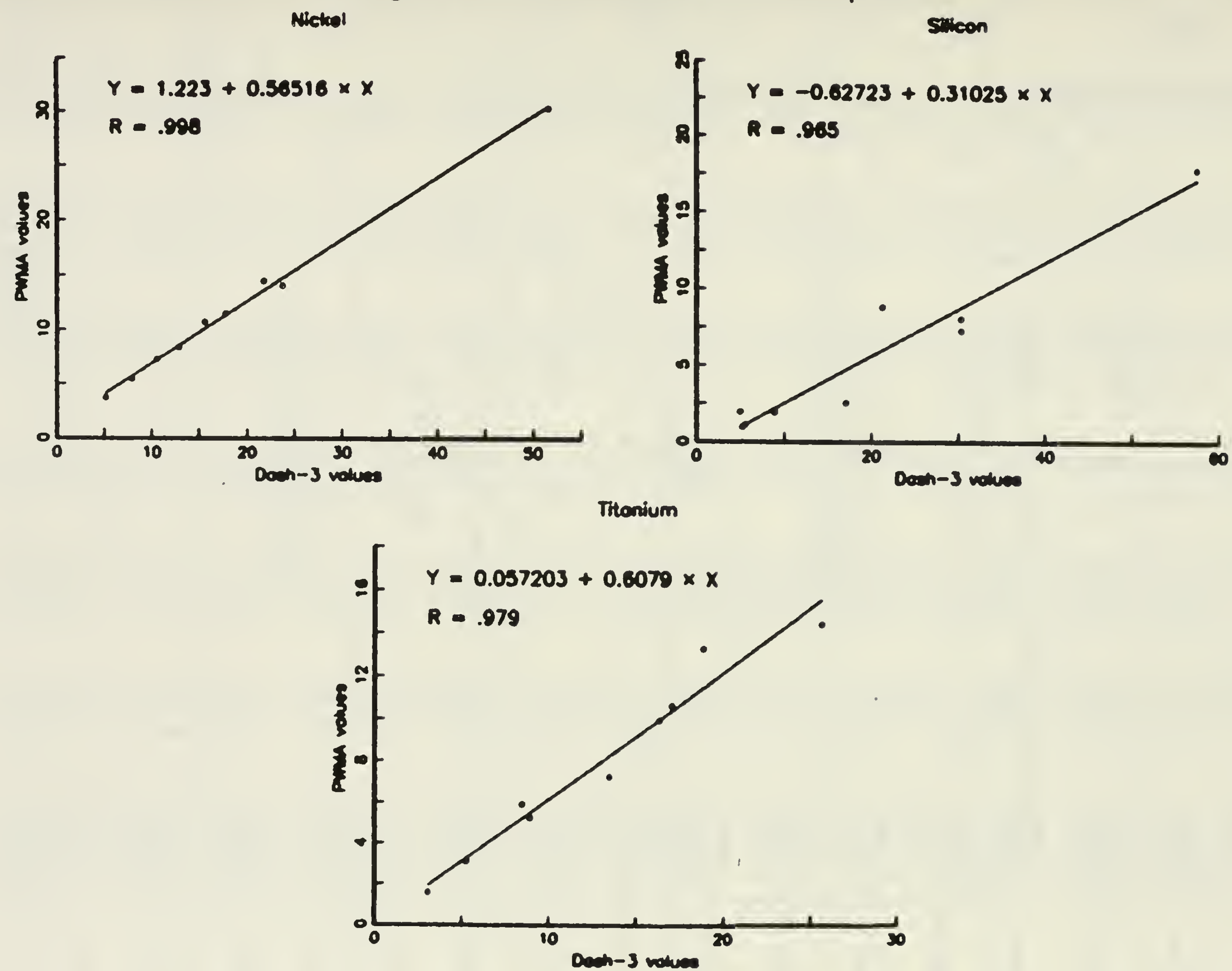


Table 2.21 Correlation Samples Summary
Overall Standard Deviations

| El | Inst | Stat | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fe | Dash-3 | Mean | 14.8 | 49.7 | 11.2 | 15.2 | 43.0 | 7.1 | 117.7 | 7.6 | 53 |
| | | StDev | 1.6 | 8.2 | 2.6 | 1.4 | 5.0 | 1.0 | 12.3 | 3.1 | 8 |
| | | Size | 26 | 26 | 28 | 22 | 22 | 25 | 26 | 20 | |
| | PWMA | Mean | 9.6 | 26.0 | 7.0 | 7.3 | 19.6 | 4.0 | 65.3 | 4.6 | 25 |
| | | StDev | 2.0 | 5.2 | 3.1 | 2.0 | 4.6 | 1.2 | 18.4 | 2.4 | 10 |
| | | Size | 130 | 130 | 130 | 125 | 125 | 125 | 120 | 105 | 1 |
| Ag | Dash-3 | Mean | 8.5 | 19.4 | 21.5 | 14.3 | 7.8 | 15.7 | .2 | .2 | |
| | | StDev | 1.4 | 3.7 | 3.5 | 1.5 | 1.7 | 1.7 | .5 | .4 | |
| | | Size | 26 | 26 | 28 | 22 | 22 | 25 | 26 | 20 | |
| | PWMA | Mean | 5.6 | 10.9 | 12.1 | 8.6 | 3.7 | 9.3 | .0 | .0 | |
| | | StDev | 2.0 | 1.7 | 2.2 | 2.8 | 1.7 | 1.4 | .0 | .0 | |
| | | Size | 130 | 130 | 130 | 125 | 125 | 125 | 120 | 105 | 1 |
| Al | Dash-3 | Mean | 29.0 | 12.0 | 11.4 | 18.2 | 3.5 | 17.1 | 36.9 | 50.2 | 23 |
| | | StDev | 3.0 | 5.5 | 2.5 | 2.6 | 1.9 | 3.0 | 4.8 | 6.2 | 3 |
| | | Size | 26 | 26 | 28 | 22 | 22 | 25 | 26 | 20 | |
| | PWMA | Mean | 14.5 | 8.2 | 9.2 | 10.2 | 4.1 | 11.7 | 21.7 | 24.4 | 16 |
| | | StDev | 6.3 | 4.6 | 4.0 | 4.5 | 3.1 | 5.3 | 7.6 | 7.6 | 6 |
| | | Size | 130 | 130 | 130 | 125 | 125 | 125 | 120 | 105 | 1 |
| Cr | Dash-3 | Mean | 10.2 | 12.0 | 2.1 | 12.6 | 12.5 | 6.1 | 3.2 | 1.9 | 1 |
| | | StDev | .7 | .8 | .7 | .9 | .9 | .8 | .4 | .9 | |
| | | Size | 26 | 26 | 28 | 22 | 22 | 25 | 26 | 20 | |
| | PWMA | Mean | 6.9 | 7.9 | 1.7 | 8.8 | 10.0 | 4.8 | 2.1 | 1.3 | 1 |
| | | StDev | 1.6 | 1.7 | .6 | 2.5 | 1.4 | .7 | .7 | .8 | |
| | | Size | 130 | 130 | 130 | 125 | 125 | 125 | 120 | 105 | 1 |
| Cu | Dash-3 | Mean | 39.3 | 17.7 | 62.3 | 14.9 | 9.5 | 19.5 | 66.7 | 46.6 | 46 |
| | | StDev | 4.1 | 6.9 | 7.7 | 1.1 | .7 | 1.0 | 3.8 | 7.2 | 6 |
| | | Size | 26 | 26 | 28 | 22 | 22 | 25 | 26 | 20 | |
| | PWMA | Mean | 29.5 | 9.3 | 41.5 | 8.3 | 4.4 | 11.4 | 39.3 | 29.1 | 31 |
| | | StDev | 6.8 | 1.8 | 9.7 | 2.5 | 5.0 | 1.9 | 9.8 | 9.7 | 12 |
| | | Size | 130 | 130 | 130 | 125 | 125 | 125 | 120 | 105 | 1 |
| Mg | Dash-3 | Mean | 12.1 | 22.1 | 38.1 | 16.7 | 44.7 | 3.8 | 29.9 | 50.6 | 45 |
| | | StDev | 1.5 | 2.4 | 4.5 | 2.9 | 6.1 | .9 | 6.9 | 13.9 | 6 |
| | | Size | 26 | 26 | 28 | 22 | 22 | 25 | 26 | 20 | |
| | PWMA | Mean | 4.8 | 11.0 | 27.3 | 8.1 | 25.5 | 1.4 | 12.3 | 24.3 | 27 |
| | | StDev | 1.6 | 4.1 | 4.6 | 4.1 | 3.9 | .7 | 4.9 | 5.2 | 2 |
| | | Size | 130 | 130 | 130 | 125 | 125 | 125 | 120 | 105 | 1 |
| Ni | Dash-3 | Mean | 10.6 | 17.8 | 51.6 | 12.9 | 5.1 | 21.7 | 23.8 | 7.9 | 15 |
| | | StDev | 1.2 | 2.0 | 5.5 | .9 | .6 | 5.2 | 1.4 | .9 | 2 |
| | | Size | 26 | 26 | 28 | 22 | 22 | 25 | 26 | 20 | |
| | PWMA | Mean | 7.3 | 11.4 | 30.2 | 8.3 | 3.7 | 14.4 | 14.0 | 5.4 | 10 |
| | | StDev | 1.2 | 2.0 | 4.9 | 1.8 | .6 | 1.6 | 2.9 | 1.5 | 2 |
| | | Size | 130 | 130 | 130 | 125 | 125 | 125 | 120 | 105 | 1 |
| Si | Dash-3 | Mean | 8.9 | 5.3 | 21.3 | 17.1 | 5.6 | 5.0 | 57.5 | 30.4 | 30 |
| | | StDev | 2.4 | 1.8 | 2.9 | 2.2 | 6.5 | 2.2 | 7.5 | 3.4 | 3 |
| | | Size | 26 | 26 | 28 | 22 | 22 | 25 | 26 | 20 | |
| | PWMA | Mean | 1.9 | 1.0 | 8.8 | 2.5 | 1.1 | 2.0 | 17.9 | 7.3 | 8 |
| | | StDev | 4.1 | 2.4 | 4.2 | 2.9 | 3.7 | 4.1 | 7.3 | 3.5 | 5 |
| | | Size | 130 | 130 | 130 | 125 | 125 | 125 | 120 | 105 | 1 |
| Ti | Dash-3 | Mean | 13.4 | 8.9 | 8.4 | 17.0 | 18.7 | 16.2 | 25.5 | 5.3 | 3 |
| | | StDev | 1.8 | 1.9 | 2.4 | 1.8 | 2.2 | 1.9 | 1.8 | 2.2 | 1 |
| | | Size | 26 | 26 | 28 | 22 | 22 | 25 | 26 | 20 | |
| | PWMA | Mean | 7.2 | 5.2 | 5.9 | 10.6 | 13.3 | 9.9 | 14.5 | 3.1 | 1 |
| | | StDev | 1.3 | 1.6 | 4.1 | 2.5 | 2.6 | 1.6 | 2.9 | 1.6 | |
| | | Size | 130 | 130 | 130 | 125 | 125 | 125 | 120 | 105 | 1 |

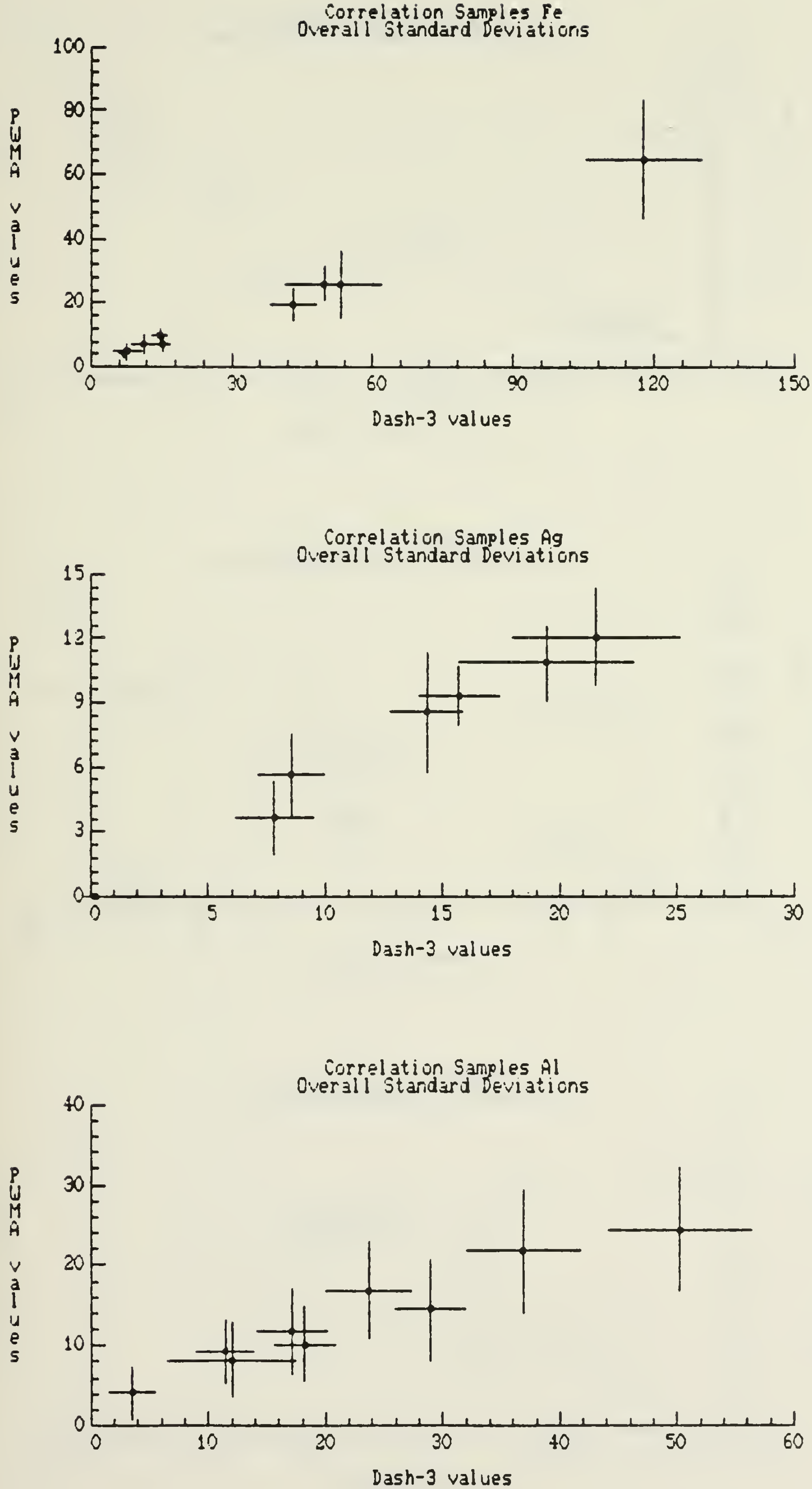

Correlation Samples Fe
Overall Standard Deviations
PWMA values
Dash-3 values
0
20
40
60
80
100
0
30
60
90
120
150
Correlation Samples Ag
Overall Standard Deviations
PWMA values
Dash-3 values
0
3
6
9
12
15
0
5
10
15
20
25
30
Correlation Samples Al
Overall Standard Deviations
PWMA values
Dash-3 values
0
10
20
30
40
0
10
20
30
40
50
60

Figure 2.4

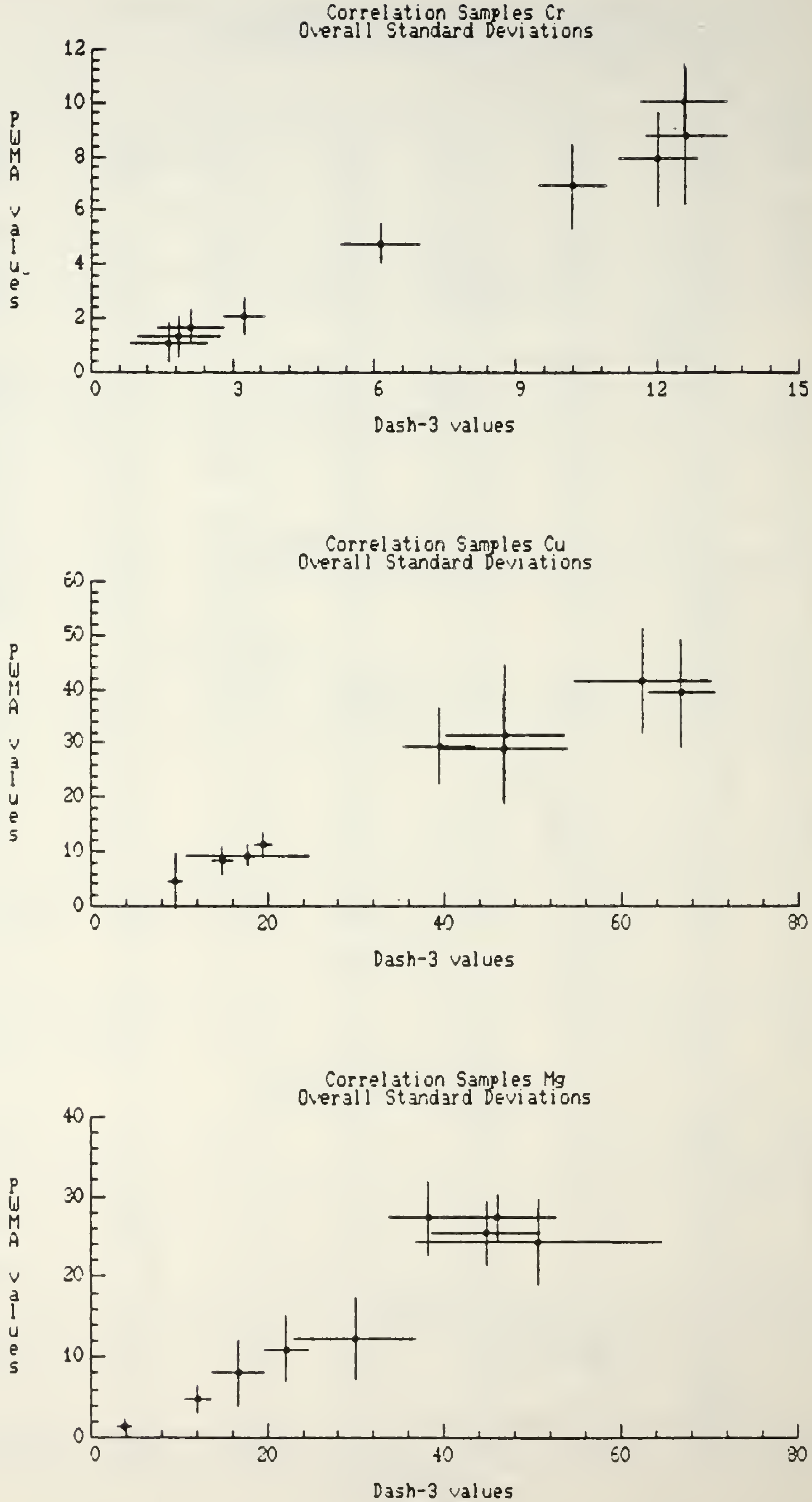

Correlation Samples Cr
Overall Standard Deviations
PWMA values
Dash-3 values
0 2 4 6 8 10 12
0 3 6 9 12 15
Correlation Samples Cu
Overall Standard Deviations
PWMA values
Dash-3 values
0 10 20 30 40 50 60
0 20 40 60 80
Correlation Samples Mg
Overall Standard Deviations
PWMA values
Dash-3 values
0 10 20 30 40
0 20 40 60 80

Figure 2.5

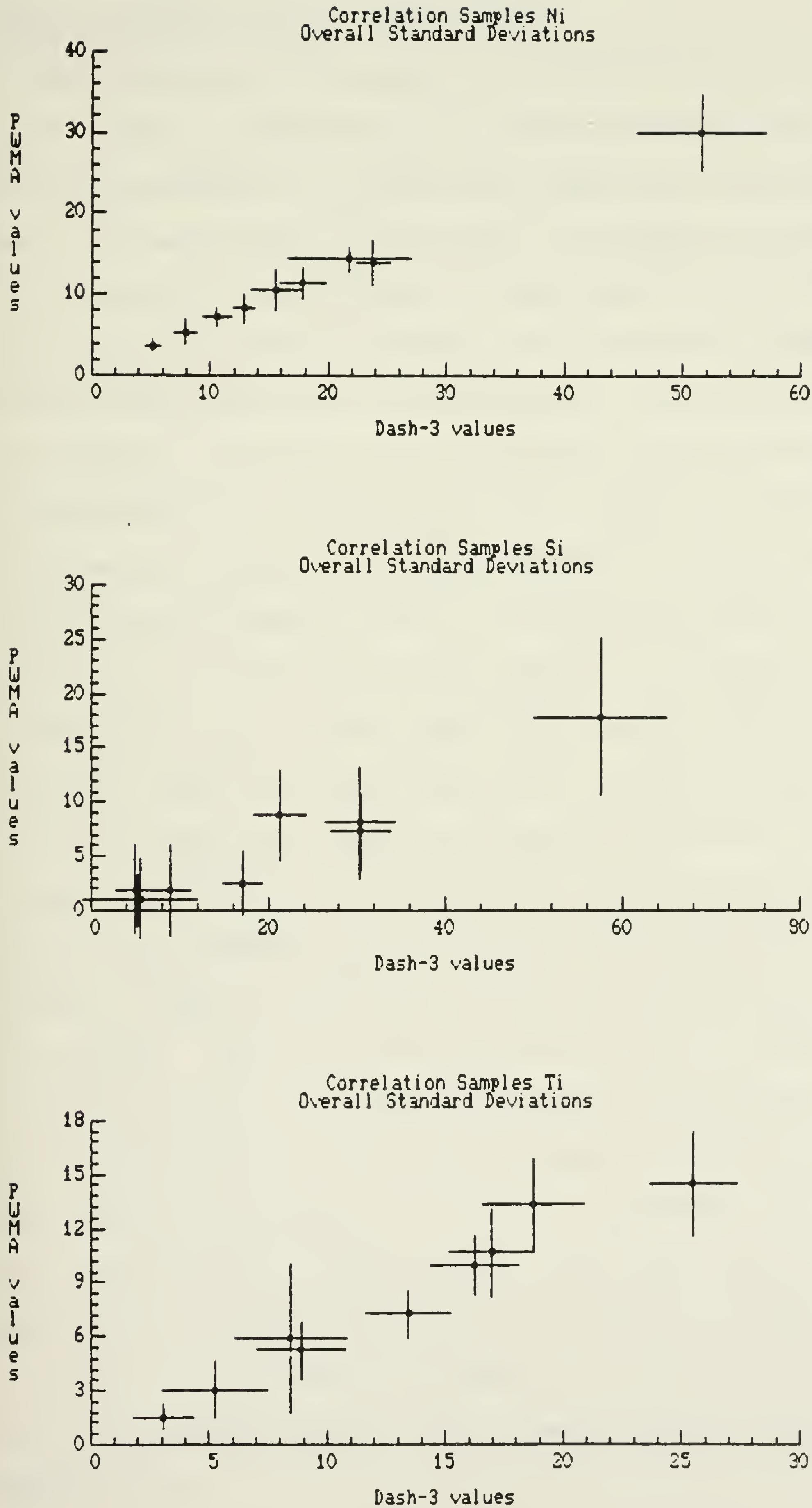

Correlation Samples Ni
Overall Standard Deviations
PWMA values
Dash-3 values
0
10
20
30
40
50
60
Correlation Samples Si
Overall Standard Deviations
PWMA values
Dash-3 values
0
5
10
15
20
25
30
40
60
80
Correlation Samples Ti
Overall Standard Deviations
PWMA values
Dash-3 values
0
3
6
9
12
15
18
5
10
15
20
25
30

Figure 2.6

## 3.1 CONVERSION FORMULAS FOR AA/AE SPECTROMETERS

The SOAP laboratories participating in the Joint Oil Analysis Program use one of two types of spectrometers viz., the Baird-Atomic A/E35U-3 atomic emission (AE) spectrometer or the Perkin-Elmer Atomic Absorption (AA) spectrometer (and a very small number of older type of instruments are sometimes used) for oil analysis. These two types of instruments use quite different operating principles for measuring the wear metal content in oil samples and hence the measurements from these two spectrometers, for the same oil sample, tend to be different. Oil analysis is used by the military services as a diagnostic maintenance tool for aircraft engines, gearboxes, hydraulic systems and other oil-wetted components of military equipment. The basic assumption behind the oil analysis program is that for a normally operating piece of equipment the rate of buildup of wear metal content in oil samples is constant; if the concentration level for a wear metal either exceeds a prescribed threshold value and/or there is a change in the rate of buildup of the wear metal, this is to be considered as an indicator of unusual wear and more frequent monitoring or a recommendation to initiate appropriate corrective action may be warranted. Thus, the wear metal history over time (operating hours since the previous oil change) is the primary data for monitoring equipment such as aircraft engines. When an aircraft moves from one base to another it is possible that the two bases use two different types of spectrometers for oil analysis. Then the analysis results from one base will not be comparable to the results from the second base for the same aircraft engine. This could be problematic unless there is a scheme available for converting AA data into "equivalent" AE data; the wear metal history can then be transformed into one set of contiguous data for monitoring purposes. In 1975, the Southwest Research Institute [ 4 ] recommended the use of the following conversion formula:

A/E35U-3 = 2 x AA

About the same time, the Naval Weapons Engineering Support Activity (NAVWESA) [3] demonstrated the feasibility of using statistical regression techniques to determine appropriate conversion formulas. In 1982 [2] we conducted a preliminary investigation to examine the efficacy of the two approaches. It was shown that the Southwest Research Institute's approach provides only a crude approximation and that regression techniques could lead to better conversion formulas. In fact, it was found that the relationship between the AA and AE readings can be very well represented by a straight line.

We now report on a more detailed study to establish the relationship between the readings from an AA spectrometer and those for an AE spectrometer. The data for this study was drawn from the monthly correlation program. The correlation program is a means, used by JOAP-TSC (Joint Oil Analysis Program - Technical Support Center, Pensacola, FL), to attest that spectrometers remain calibrated and standardized within limits. Approximately 200 AE laboratories and about 45 AA laboratories participate in the program. Each month, the TSC sends out two synthesized samples and two used oil samples (sometimes the used oil samples are in reality mixtures of used and synthesized samples) to these laboratories for analysis. The results are sent back to JOAP-TSC; the actual number of laboratories submitting data varies from month to month. The TSC compiles the data and issues a monthly report that consists (among other things) of tables of spectrometric measurements for each of ten wear metals viz., Fe, Ag, Al, Cr, Cu, Mg, Si, Ti, Mo and Ni; the report also includes two sets of trimmed means (for the ten wear metals) computed by separately pooling all the data for the AA and AE laboratories. We selected (from the monthly reports for the period July 83 - August 85) 20 sets of 44 pairs of data (each pair consists of the AA mean and the corresponding AE mean for a particular month), one set for each element and sample type (synthesized or used oil) combination.

The AA mean was treated as the independent variable and the AE mean as the corresponding dependent variable; a simple linear regression technique was applied, to determine the "best" fitting straight line. The results are shown in Figures 3.1 - 3.10 for synthesized samples and Figures 3.11 - 3.20 for used oil samples. Table 3.1 summarizes the intercept and slope parameters of the fitted lines and the observed correlation between the average AA reading and the average AE reading. It is clear that the fitted straight lines provide quite accurate representations for the relationship between the AA and AE readings; with the exception of one case (molibdinum for used oil samples) the correlations are all above .93 and in most cases close to .99.

As a check on how the fitted lines may have changed since our previous study, we combined the 24 pairs of old data (drawn from the monthly reports for the period March 80 - February 81) for the elements Fe, Ag, Al, Cr, Cu and Mg with the data for the current investigation and fit straightlines to each of the six sets of 68 pairs of data. The resulting intercept and slope parameters are in Table 3.2. For purposes of comparison, the slope parameters for the newer data (extracted from Table 1) are shown in parentheses. No significant changes in the parameters of the fitted lines are evident.

Table 3.3 generated using the fitted straight lines, are included for the convenience of oil analysis laboratory personnel in converting AA measurements into AE measurements for used oil samples.

ESTIMATED LINEAR RELATIONSHIP BETWEEN THE ATOMIC ABSORPTION AND THE ATOMIC EMISSION SPECTROMETERS

| ELEMENT | ESTIMATED VALUE OF THE INTERCEPT | ESTIMATED VALUE OF THE SLOPE | CORRELATION BETWEEN AA AND AE READINGS |
|---|---|---|---|
| | SYNTHESIZED SAMPLES | | |
| IRON | -2.5 | 1.07 | .99+ |
| SILVER | 0.1 | 0.88 | .99+ |
| ALUMINUM | 0.7 | 0.99 | .99 |
| CHROMIUM | 0.1 | 0.98 | .99 |
| COPPER | 1.4 | 0.96 | .99 |
| MAGNESIUM | 0.5 | 0.95 | .99+ |
| SILICON | 2.3 | 0.96 | .99 |
| TITANIUM | 0.7 | 0.94 | .99+ |
| MOLIBDINUM | -1.4 | 1.01 | .99 |
| NICKEL | -0.6 | 1.03 | .99+ |
| | USED OIL SAMPLES | | |
| IRON | 3.8 | 1.14 | .99 |
| SILVER | -0.5 | 1.81 | .99+ |
| ALUMINUM | -1.7 | 1.39 | .99 |
| CHROMIUM | -0.2 | 1.38 | .98 |
| COPPER | -0.4 | 1.74 | .99 |
| MAGNESIUM | 1.9 | 1.58 | .98 |
| SILICON | -2.0 | 1.64 | .97 |
| TITANIUM | 0.0 | 1.95 | .99+ |
| MOLIBDINUM | 0.8 | 1.01 | .93 |
| NICKEL | 0.0 | 1.05 | .84 |

THE ABOVE ESTIMATES ARE BASED ON 44 DATA PAIRS - 22 MONTHLY CORRELATION REPORTS DURING THE PERIOD JUL83-AUG85; IN EACH MONTH TWO SYNTHESIZED SAMPLES AND TWO USED OIL SAMPLES WERE ANALYZED. THE AVERAGE READINGS FOR ALL AA-LABS AND THE AVERAGE FOR THE AE-LABS WERE USED TO DETERMINE THE LINEAR RELATIONSHIP.

TABLE 3.1

ESTIMATED LINEAR RELATIONSHIP BETWEEN THE ATOMIC ABSORPTION AND THE ATOMIC EMISSION SPECTROMETERS

| ELEMENT | ESTIMATED VALUE OF THE INTERCEPT | ESTIMATED VALUE OF THE SLOPE | CORRELATION BETWEEN AA AND AE READINGS |
|---|---|---|---|
| | S Y N T H E S I Z E D S A M P L E S | | |
| IRON | -1.8 | 1.06 (1.07) | .99+ |
| SILVER | 0.3 | 0.92 (0.88) | .99+ |
| ALUMINUM | 1.2 | 0.97 (0.99) | .99 |
| CHROMIUM | 0.1 | 1.01 (0.99) | .99 |
| COPPER | 1.8 | 0.95 (0.96) | .99+ |
| MAGNESIUM | 1.4 | 0.94 (1.03) | .99+ |
| | U S E D O I L S A M P L E S | | |
| IRON | 4.8 | 1.14 (1.14) | .99+ |
| SILVER | -0.5 | 1.80 (1.81) | .99+ |
| ALUMINUM | -1.3 | 1.36 (1.39) | .99 |
| CHROMIUM | 0.5 | 1.12 (1.38) | .99 |
| COPPER | -0.8 | 1.73 (1.74) | .97 |
| MAGNESIUM | 3.9 | 1.31 (1.58) | .98 |

THE ABOVE ESTIMATES ARE BASED ON 68 DATA PAIRS - 22 MONTHLY CORRELATION REPORTS DURING THE PERIOD JUL83-AUG85 AND 12 REPORTS FOR THE PERIOD MAR80-FEB81; IN EACH MONTH TWO SYNTHESIZED SAMPLES AND TWO USED OIL SAMPLES WERE ANALYZED. THE AVERAGE READINGS FOR ALL AA-LABS AND THE AVERAGE FOR THE AE-LABS WERE USED TO DETERMINE THE LINEAR RELATIONSHIP.

TABLE 3.2

TABLE FOR CONVERSION OF AA READINGS (PPM)
INTO EQUIVALENT AE READINGS (PPM)

| | WEARMETAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| AE→ / AA↓ | Fe | Ag | Al | Cr | Cu | Mg | Si | Ti | Mo | N |
| 0 | 3.8 | 0.0 | 0.0 | 0.0 | 0.0 | 1.9 | 0.0 | 0.0 | 0.8 | 0 |
| 2 | 6.1 | 3.1 | 1.1 | 2.6 | 3.1 | 5.1 | 1.3 | 3.9 | 2.8 | 2 |
| 4 | 8.4 | 6.7 | 3.9 | 5.3 | 6.6 | 8.2 | 4.6 | 7.8 | 4.8 | 4 |
| 6 | 10.6 | 10.4 | 6.6 | 8.1 | 10.0 | 11.4 | 7.8 | 11.7 | 6.9 | 6 |
| 8 | 12.9 | 14.0 | 9.4 | 10.8 | 13.5 | 14.5 | 11.1 | 15.6 | 8.9 | 8 |
| 10 | 15.2 | 17.6 | 12.2 | 13.6 | 17.0 | 17.7 | 14.4 | 19.5 | 10.9 | 10 |
| 12 | 17.5 | 21.2 | 15.0 | 16.4 | 20.5 | 20.9 | 17.7 | 23.4 | 12.9 | 12 |
| 14 | 19.8 | 24.8 | 17.8 | 19.1 | 24.0 | 24.0 | 21.0 | 27.3 | 14.9 | 14 |
| 16 | 22.0 | 28.5 | 20.5 | 21.9 | 27.4 | 27.2 | 24.2 | 31.2 | 17.0 | 16 |
| 18 | 24.3 | 32.1 | 23.3 | 24.6 | 30.9 | 30.3 | 27.5 | 35.1 | 19.0 | 18 |
| 20 | 26.6 | 35.7 | 26.1 | 27.4 | 34.4 | 33.5 | 30.8 | 39.0 | 21.0 | 21 |
| 22 | 28.9 | 39.3 | 28.9 | 30.2 | 37.9 | 36.7 | 34.1 | 42.9 | 23.0 | 23 |
| 24 | 31.3 | 42.9 | 31.7 | 32.9 | 41.4 | 39.8 | 37.4 | 46.8 | 25.0 | 25 |
| 26 | 33.4 | 46.6 | 34.4 | 35.7 | 44.8 | 43.0 | 40.6 | 50.7 | 27.1 | 27 |
| 28 | 35.7 | 50.2 | 37.2 | 38.4 | 48.3 | 46.1 | 43.9 | 54.6 | 29.1 | 29 |
| 30 | 38.0 | 53.8 | 40.0 | 41.2 | 51.8 | 49.3 | 47.2 | 58.5 | 31.1 | 31 |
| 35 | 47.7 | 62.9 | 47.0 | 48.1 | 60.5 | 57.2 | 55.4 | 68.3 | 36.2 | 36 |
| 40 | 49.4 | 71.9 | 53.9 | 55.0 | 69.2 | 65.1 | 63.1 | 78.0 | 41.2 | 42 |
| 45 | 55.1 | 81.0 | 60.9 | 61.9 | 77.9 | 73.0 | 71.8 | 87.8 | 46.3 | 47 |
| 50 | 60.8 | 90.0 | 67.8 | 68.8 | 86.6 | 80.9 | 80.0 | 97.5 | 51.3 | 52 |
| 55 | 66.5 | 99.1 | 74.8 | 75.7 | 95.3 | 88.8 | 88.2 | 107.3 | 56.4 | 57 |
| 60 | 72.2 | 108.1 | 81.7 | 82.6 | 104.0 | 96.7 | 96.4 | 117.0 | 61.4 | 63 |
| 65 | 77.9 | 117.2 | 88.7 | 89.5 | 112.7 | 104.6 | 104.6 | 126.8 | 66.5 | 68 |
| 70 | 83.6 | 126.2 | 95.6 | 96.4 | 121.4 | 112.5 | 112.8 | 136.5 | 71.5 | 73 |
| 75 | 89.3 | 135.3 | 102.6 | 103.3 | 130.1 | 120.4 | 121.0 | 146.3 | 76.6 | 78 |
| 80 | 95.0 | 144.3 | 109.5 | 110.2 | 138.8 | 128.3 | 129.2 | 156.0 | 81.6 | 84 |
| 85 | 100.7 | 153.4 | 116.5 | 117.1 | 147.5 | 136.2 | 137.4 | 165.8 | 86.7 | 89 |
| 90 | 106.4 | 162.4 | 123.4 | 124.0 | 156.2 | 144.1 | 145.6 | 175.5 | 91.7 | 94 |
| 95 | 112.1 | 171.5 | 130.4 | 130.9 | 164.9 | 152.0 | 153.8 | 185.3 | 96.8 | 99 |
| 100 | 117.8 | 180.5 | 137.3 | 137.8 | 173.6 | 159.9 | 162.0 | 195.0 | 101.8 | 105 |

TABLE 3.3

ple Regression of FEAE on FEAA

| ameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| ercept | -2.51853 | 0.766642 | -3.28515 | 2.06182E-3 |
| pe | 1.06569 | 0.0163169 | 65.3122 | 0 |

Analysis of Variance

| rce | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| el | 31743.537 | 1 | 31743.537 | 4265.686 |
| or | 312.54725 | 42 | 7.44160 | |
| al (Corr.) | 32056.084 | 43 | | |

relation Coefficient = 0.995113
d. Error of Est. = 2.72793

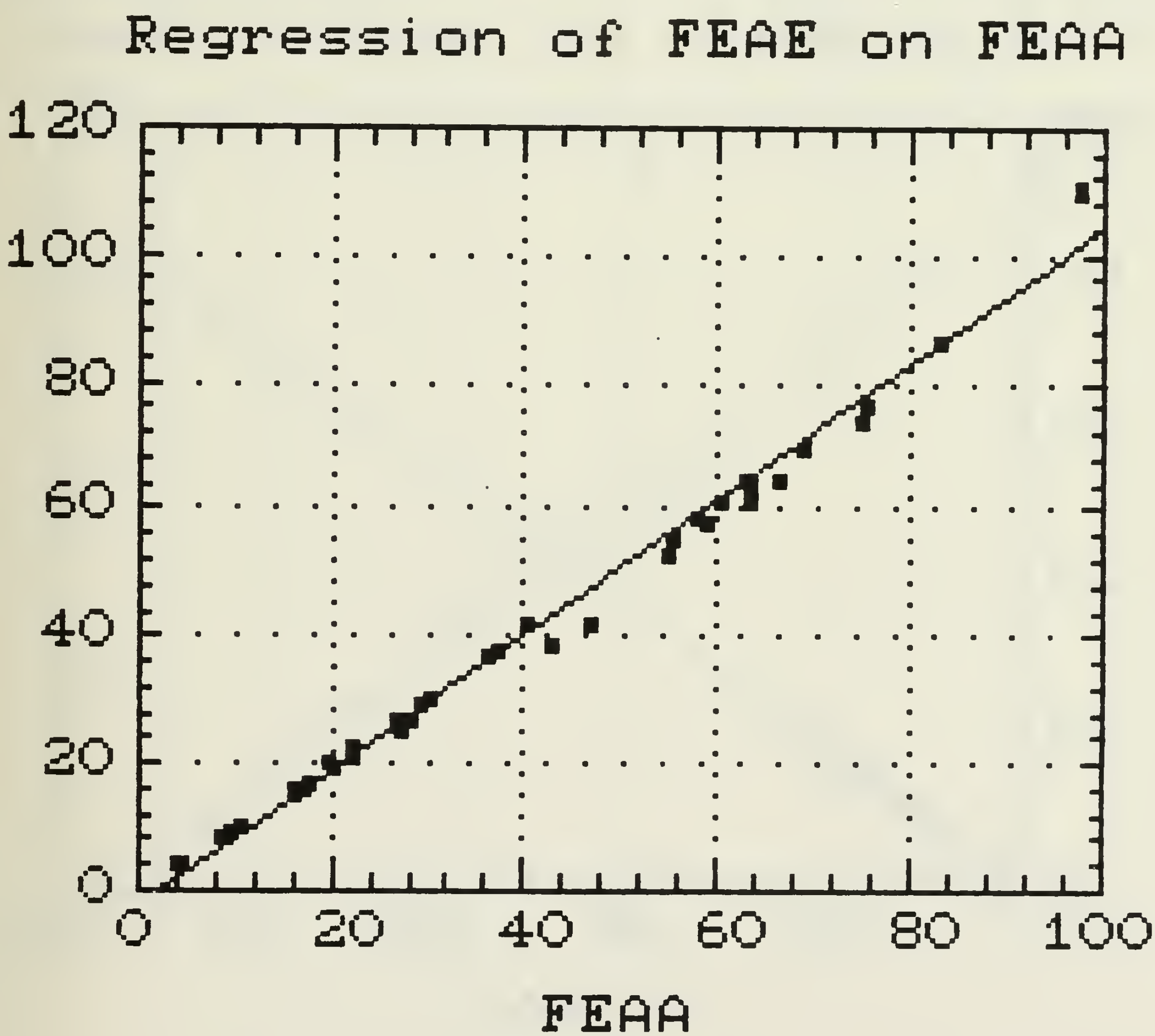



FIGURE 3.1

Simple Regression of AGAE on AGAA

| Parameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| Intercept | 0.0854417 | 0.202732 | 0.421453 | 0.675574 |
| Slope | 0.881858 | 8.10437E-3 | 108.813 | 0 |

Analysis of Variance

| Source | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| Model | 12098.642 | 1 | 12098.642 | 11840.174 |
| Error | 42.916849 | 42 | 1.021830 | |
| Total (Corr.) | 12141.559 | 43 | | |

Correlation Coefficient = 0.998231
Stnd. Error of Est. = 1.01086

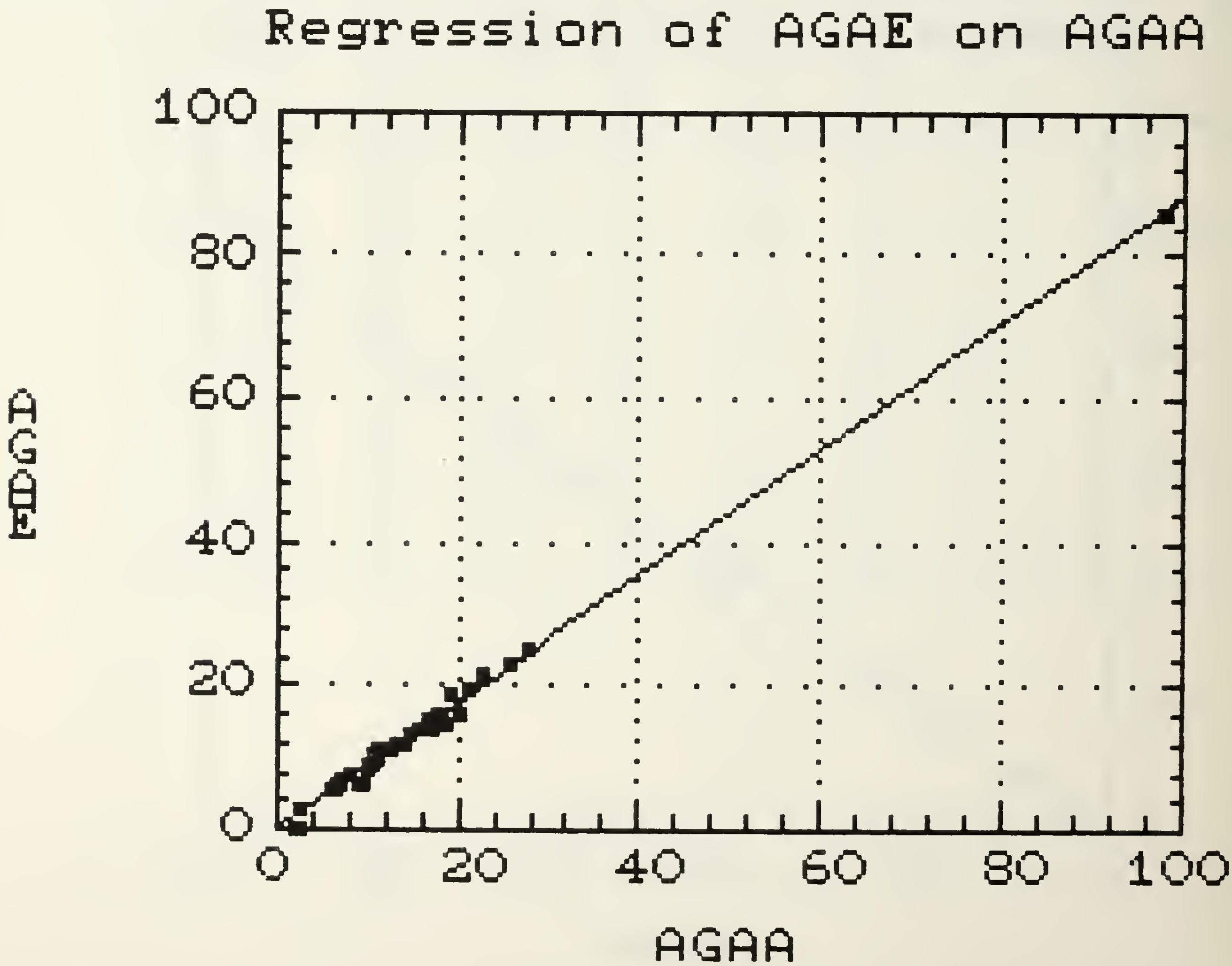



FIGURE 3.2

ple Regression of ALAE on ALAA

| ameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| ercept | 0.707248 | 0.662374 | 1.06775 | 0.291733 |
| pe | 0.988422 | 0.0178194 | 55.469 | 0 |

Analysis of Variance

| rce | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| el | 18466.452 | 1 | 18466.452 | 3076.809 |
| or | 252.07642 | 42 | 6.00182 | |
| al (Corr.) | 18718.528 | 43 | | |

relation Coefficient = 0.993244
d. Error of Est. = 2.44986

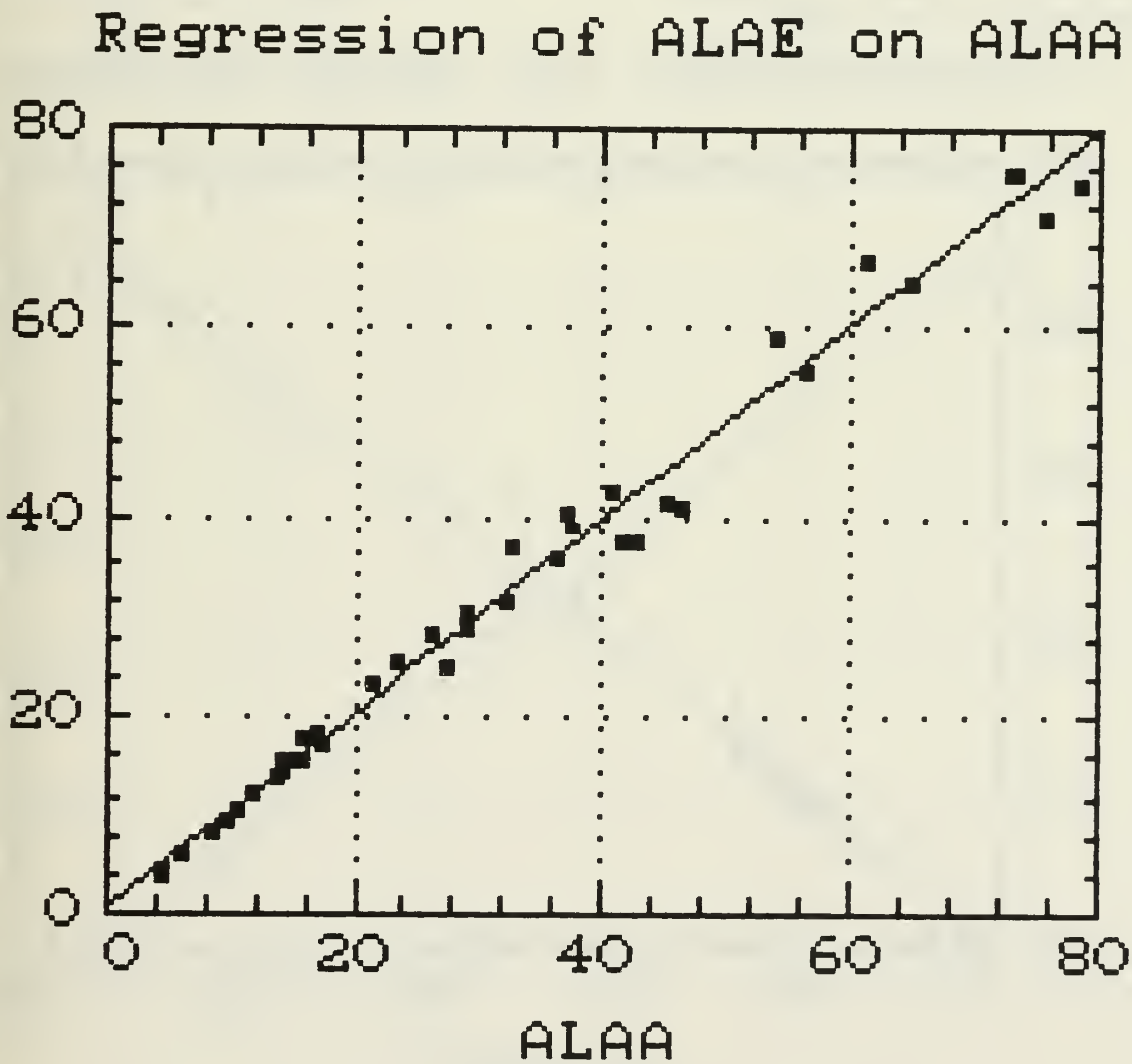



FIGURE 3.3

Simple Regression of CRAE on CRAA

| Parameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| Intercept | 0.135849 | 0.508341 | 0.26724 | 0.790592 |
| Slope | 0.978808 | 0.023484 | 41.6798 | 0 |

Analysis of Variance

| Source | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| Model | 5111.1268 | 1 | 5111.1268 | 1737.2052 |
| Error | 123.57050 | 42 | 2.94215 | |
| Total (Corr.) | 5234.6973 | 43 | | |

Correlation Coefficient = 0.988126
Stnd. Error of Est. = 1.71527

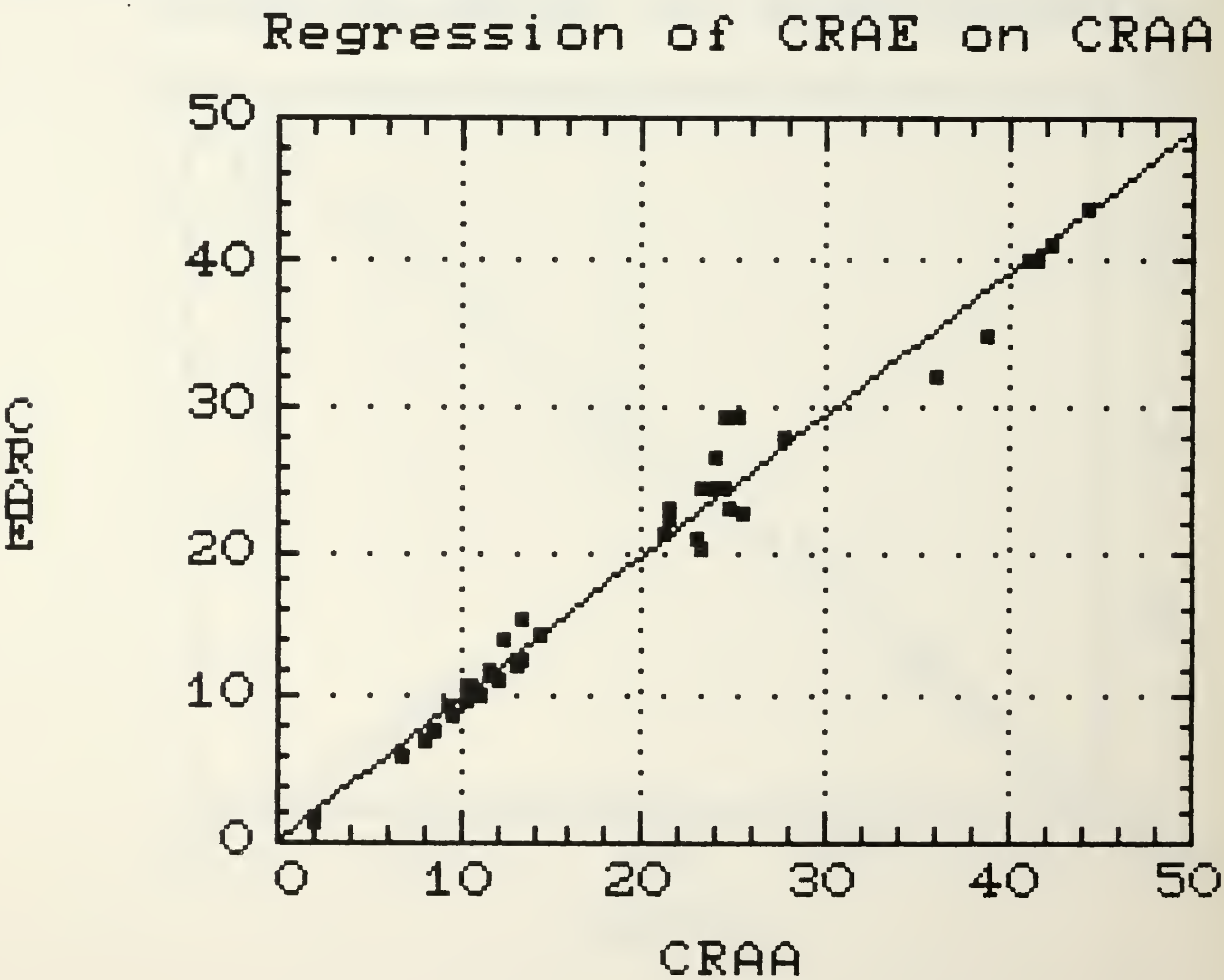



FIGURE 3.4

mple Regression of CUAE on CUAA

| rameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| tercept | 1.41253 | 0.476752 | 2.96282 | 5.00191E-3 |
| ope | 0.959073 | 0.010567 | 90.7608 | 0 |

Analysis of Variance

| urce | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| del | 30537.784 | 1 | 30537.784 | 8237.517 |
| ror | 155.70068 | 42 | 3.70716 | |
| tal (Corr.) | 30693.484 | 43 | | |

rrelation Coefficient = 0.99746
nd. Error of Est. = 1.9254

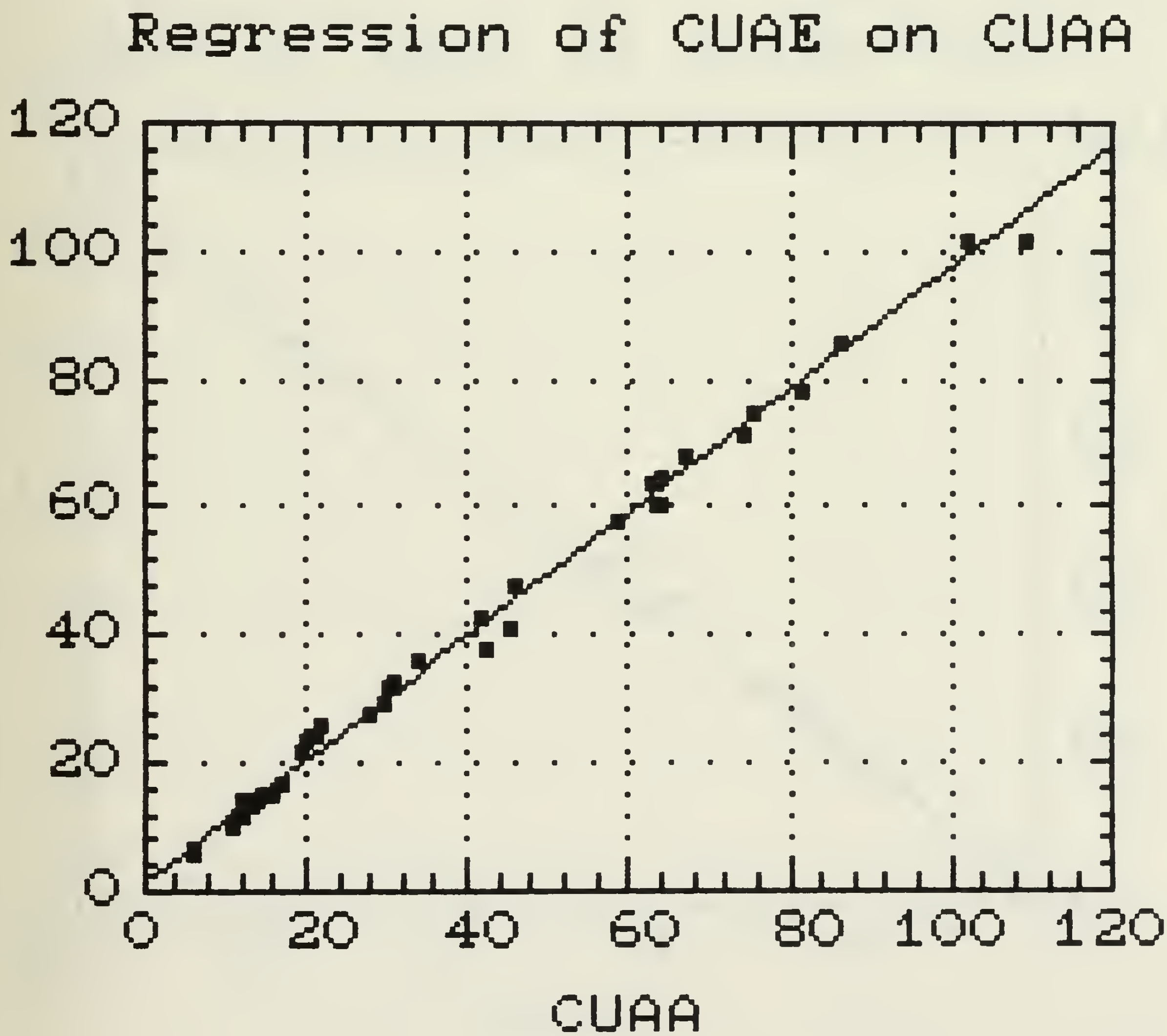



FIGURE 3.5

Simple Regression of MGAE on MGAA

| Parameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| Intercept | 0.488709 | 0.621575 | 0.786243 | 0.436139 |
| Slope | 0.953173 | 0.0124572 | 76.5156 | 0 |

Analysis of Variance

| Source | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| Model | 23922.273 | 1 | 23922.273 | 5854.642 |
| Error | 171.61348 | 42 | 4.08604 | |
| Total (Corr.) | 24093.886 | 43 | | |

Correlation Coefficient = 0.996432
Stnd. Error of Est. = 2.02139

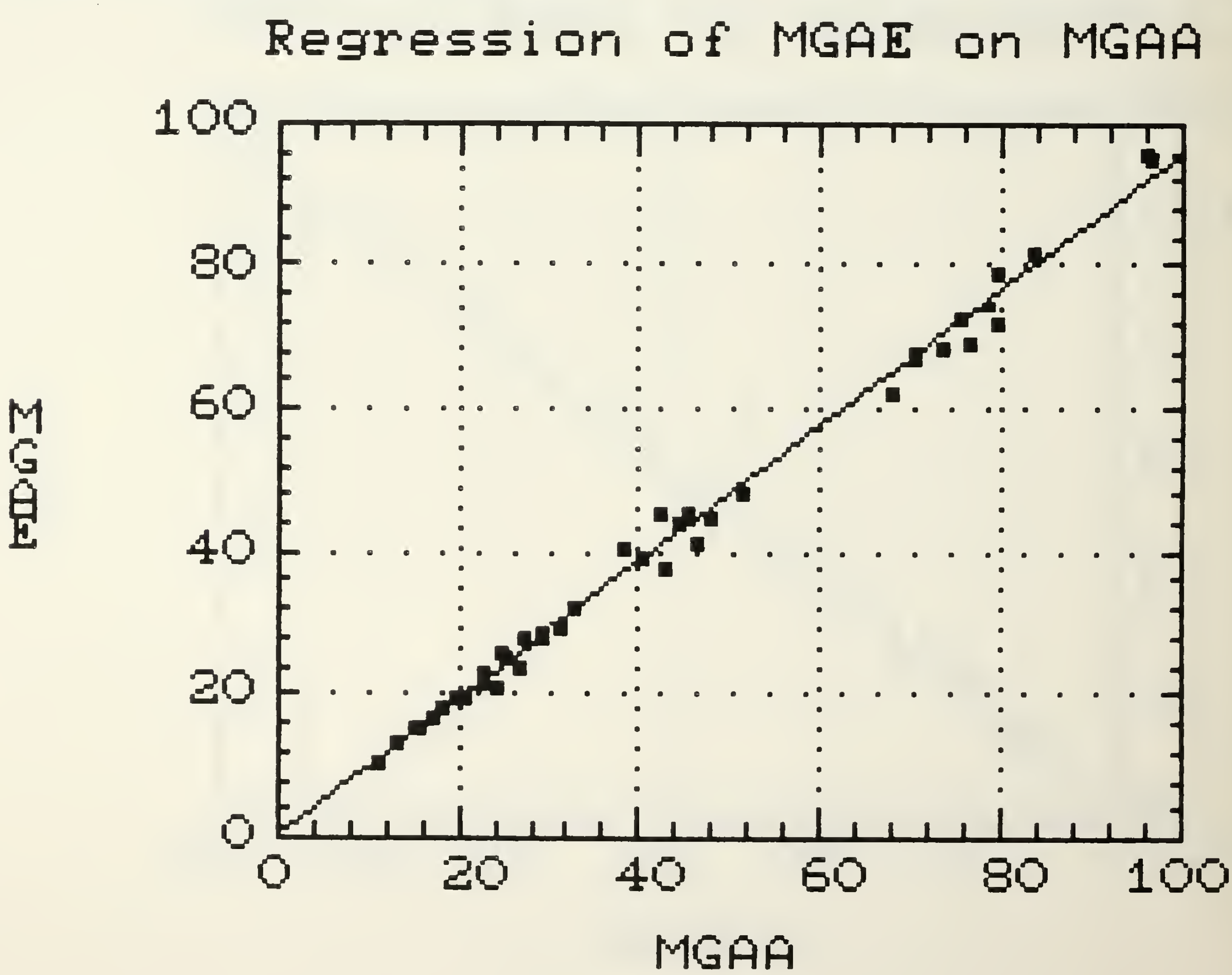



FIGURE 3.6

mple Regression of SIAE on SIAA

| rameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| tercept | 2.31468 | 1.55688 | 1.48674 | 0.144554 |
| ope | 0.964311 | 0.0168347 | 57.2813 | 0 |

Analysis of Variance

| urce | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| del | 128410.07 | 1 | 128410.07 | 3281.15 |
| ror | 1643.7004 | 42 | 39.1357 | |
| tal (Corr.) | 130053.77 | 43 | | |

rrelation Coefficient = 0.993661
nd. Error of Est. = 6.25586

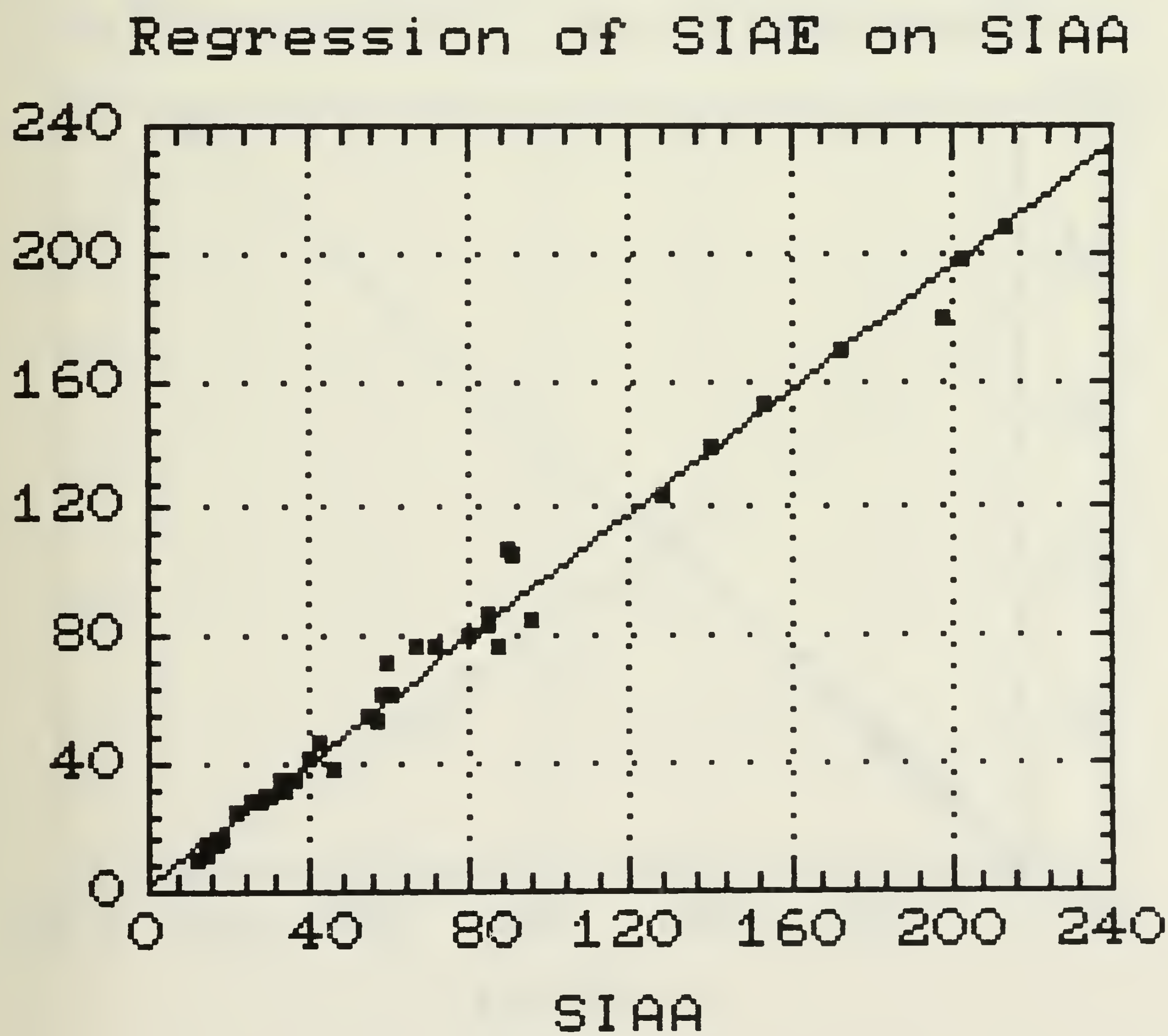



FIGURE 3.7

Simple Regression of TIAE on TIAA

| Parameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| Intercept | 0.697692 | 0.229872 | 3.03514 | 4.11604E-3 |
| Slope | 0.938799 | 7.81236E-3 | 120.168 | 0 |

Analysis of Variance

| Source | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| Model | 19170.040 | 1 | 19170.040 | 14440.439 |
| Error | 55.756038 | 42 | 1.327525 | |
| Total (Corr.) | 19225.796 | 43 | | |

Correlation Coefficient = 0.998549
Stnd. Error of Est. = 1.15218

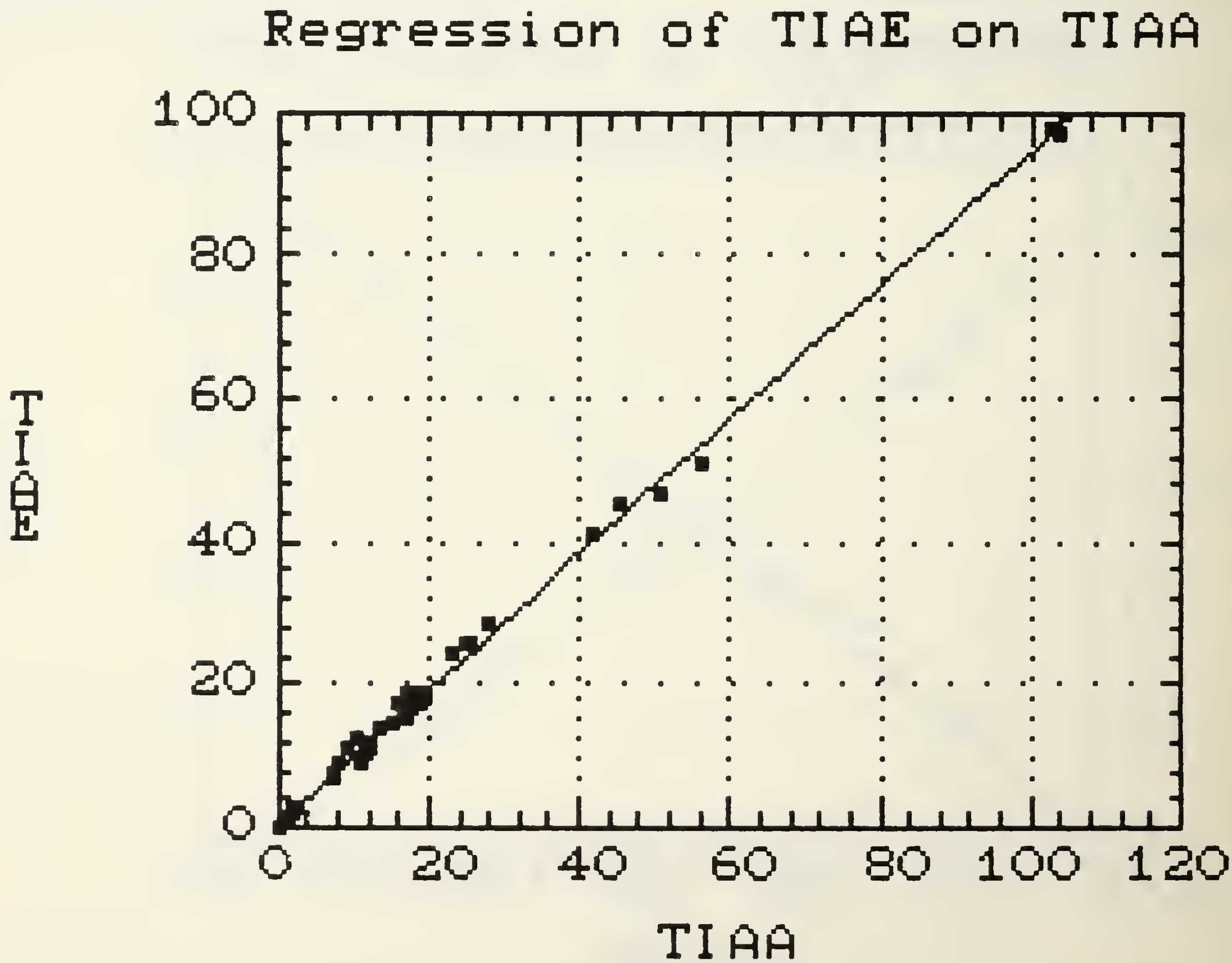



FIGURE 3.8

mple Regression of MOAE on MOAA

| rameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| tercept | - 1.40336 | 0.438983 | - 3.19684 | 2.6399E-3 |
| ope | 1.01132 | 0.0243324 | 41.5625 | 0 |

Analysis of Variance

| urce | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| del | 5114.2150 | 1 | 5114.2150 | 1727.4444 |
| ror | 124.34382 | 42 | 2.96057 | |
| tal (Corr.) | 5238.5589 | 43 | | |

rrelation Coefficient = 0.988061
nd. Error of Est. = 1.72063

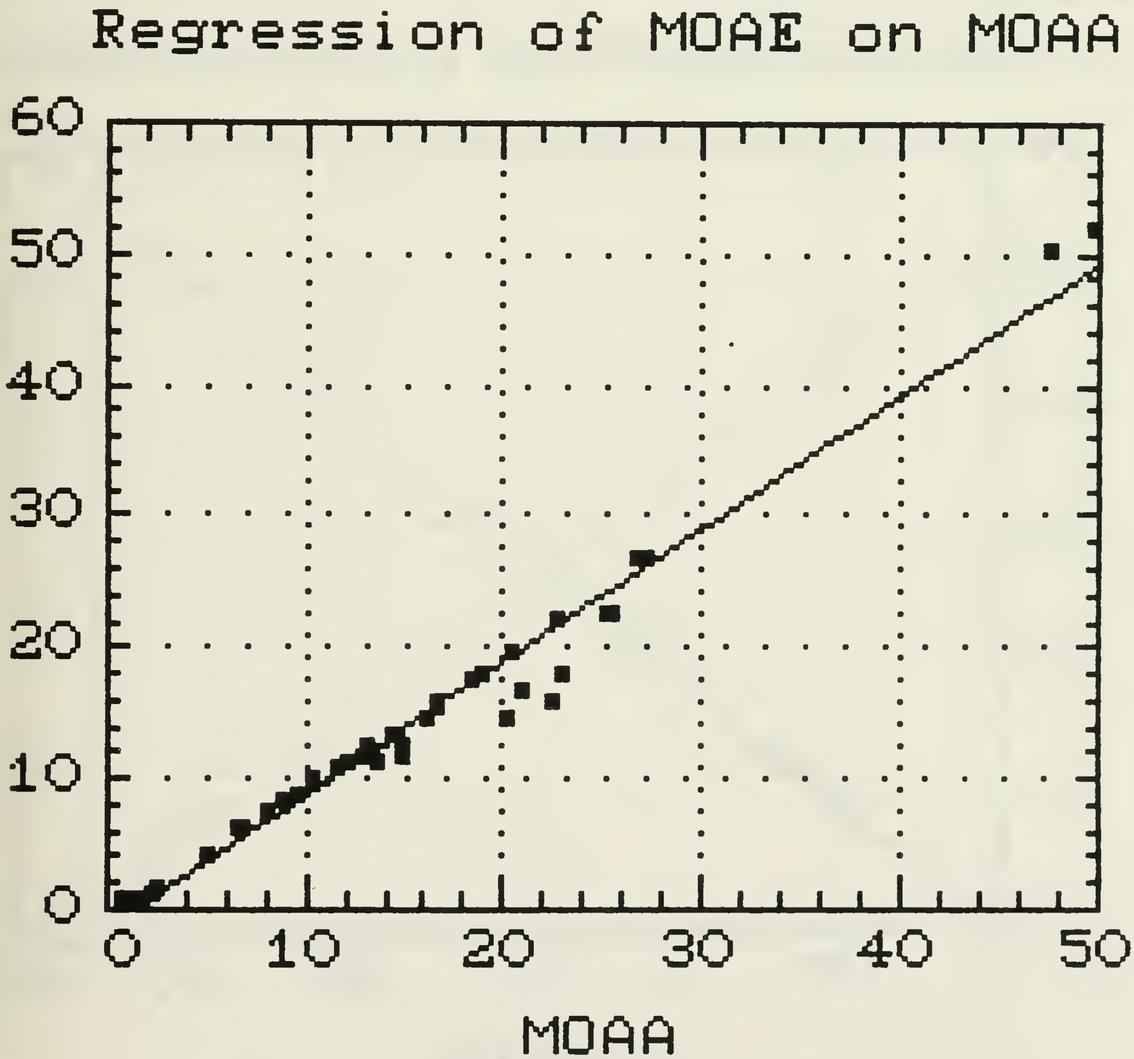



FIGURE 3.9

Simple Regression of NIAE on NIAA

| Parameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| Intercept | - 0.569596 | 0.252643 | - 2.25455 | 0.0294358 |
| Slope | 1.03343 | 0.0127757 | 80.8904 | 0 |

Analysis of Variance

| Source | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| Model | 5167.3993 | 1 | 5167.3993 | 6543.2506 |
| Error | 33.168647 | 42 | .789730 | |
| Total (Corr.) | 5200.5680 | 43 | | |

Correlation Coefficient = 0.996806
Stnd. Error of Est. = 0.888667

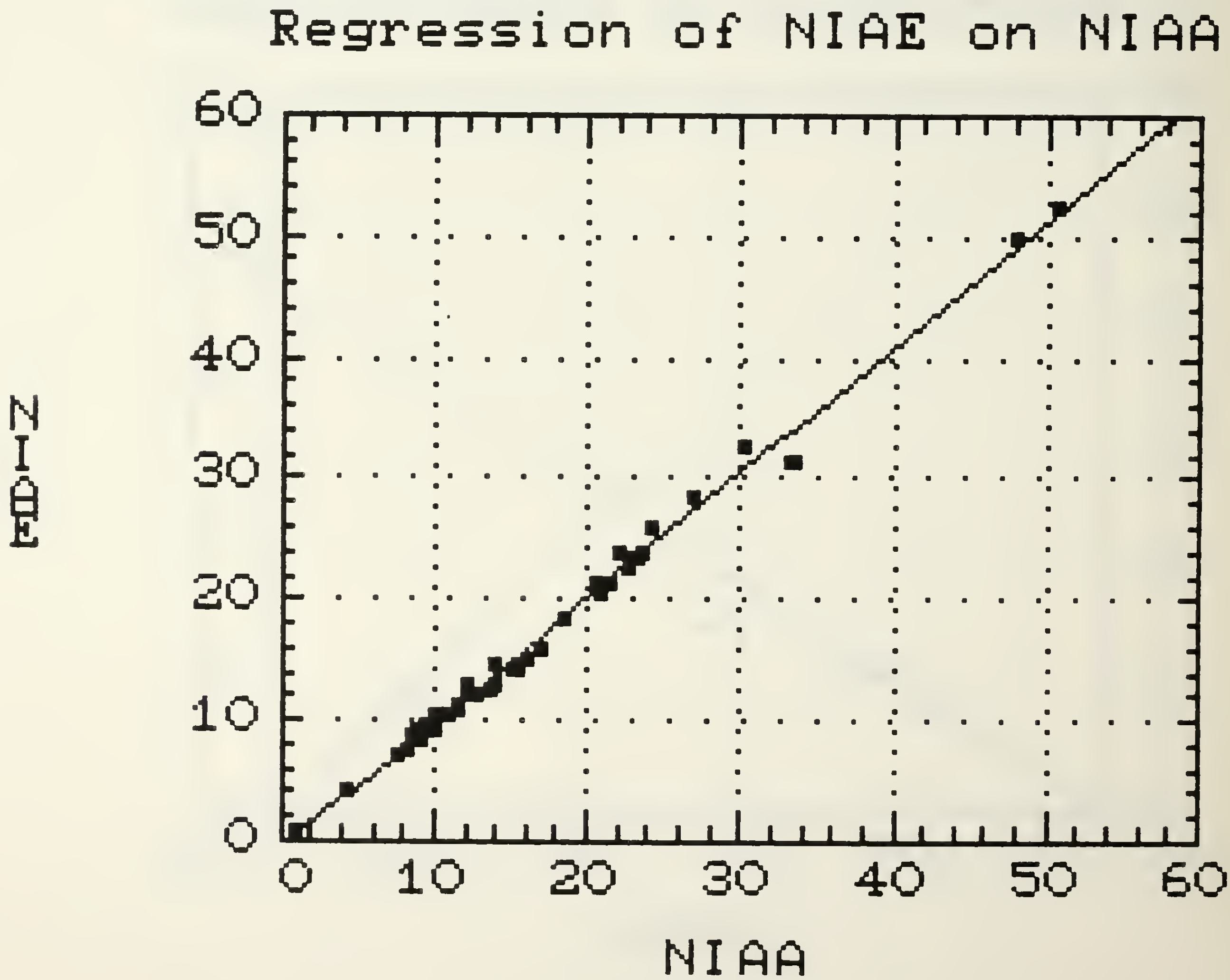



FIGURE 3.10

ple Regression of FEAEU on FEAAU

| ameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| ercept | 3.77342 | 0.581967 | 6.4839 | 7.99254E-8 |
| pe | 1.14304 | 0.0242008 | 47.2317 | 0 |

Analysis of Variance

| rce | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| el | 22468.718 | 1 | 22468.718 | 2230.837 |
| or | 423.01890 | 42 | 10.07188 | |
| al (Corr.) | 22891.737 | 43 | | |

relation Coefficient = 0.990717
d. Error of Est. = 3.17362

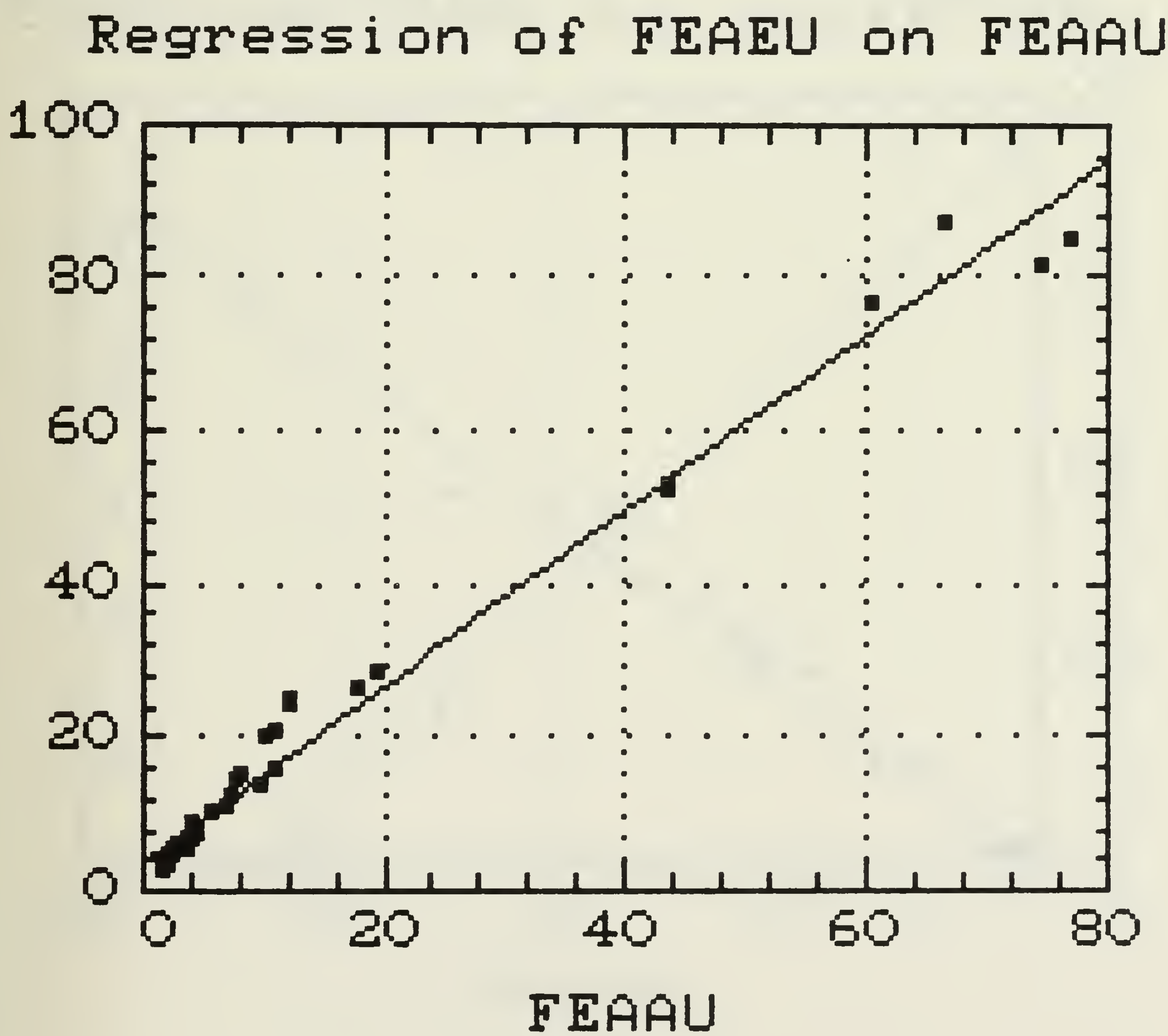



FIGURE 3.11

Simple Regression of AGAEU on AGAAU

| Parameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| Intercept | -0.535963 | 0.267933 | -2.00036 | 0.0519541 |
| Slope | 1.80884 | 0.026556 | 68.114 | 0 |

Analysis of Variance

| Source | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| Model | 10836.532 | 1 | 10836.532 | 4639.524 |
| Error | 98.099369 | 42 | 2.335699 | |
| Total (Corr.) | 10934.632 | 43 | | |

Correlation Coefficient = 0.995504
Stnd. Error of Est. = 1.5283

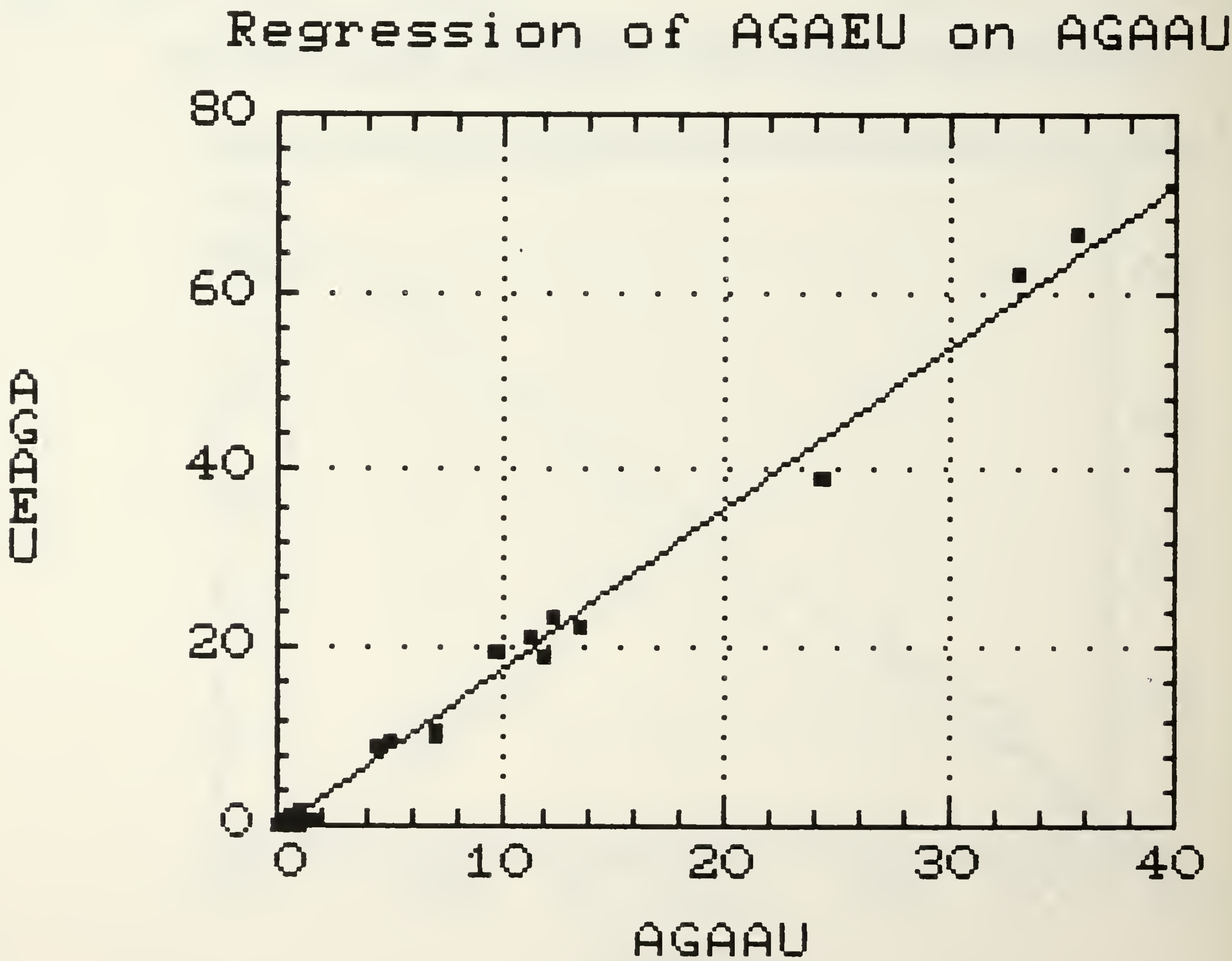



FIGURE 3.12

mple Regression of ALAEU on ALAAU

| rameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| tercept | - 1.67893 | 0.172249 | -.9.74711 | 2.39697E-12 |
| ope | 1.39112 | 0.037462 | 37.1342 | 0 |

Analysis of Variance

| rce | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| del | 847.1791 | 1 | 847.1791 | 1378.9465 |
| ror | 25.803410 | 42 | .614367 | |
| tal (Corr.) | 872.98250 | 43 | | |

rrelation Coefficient = 0.98511
d. Error of Est. = 0.783816

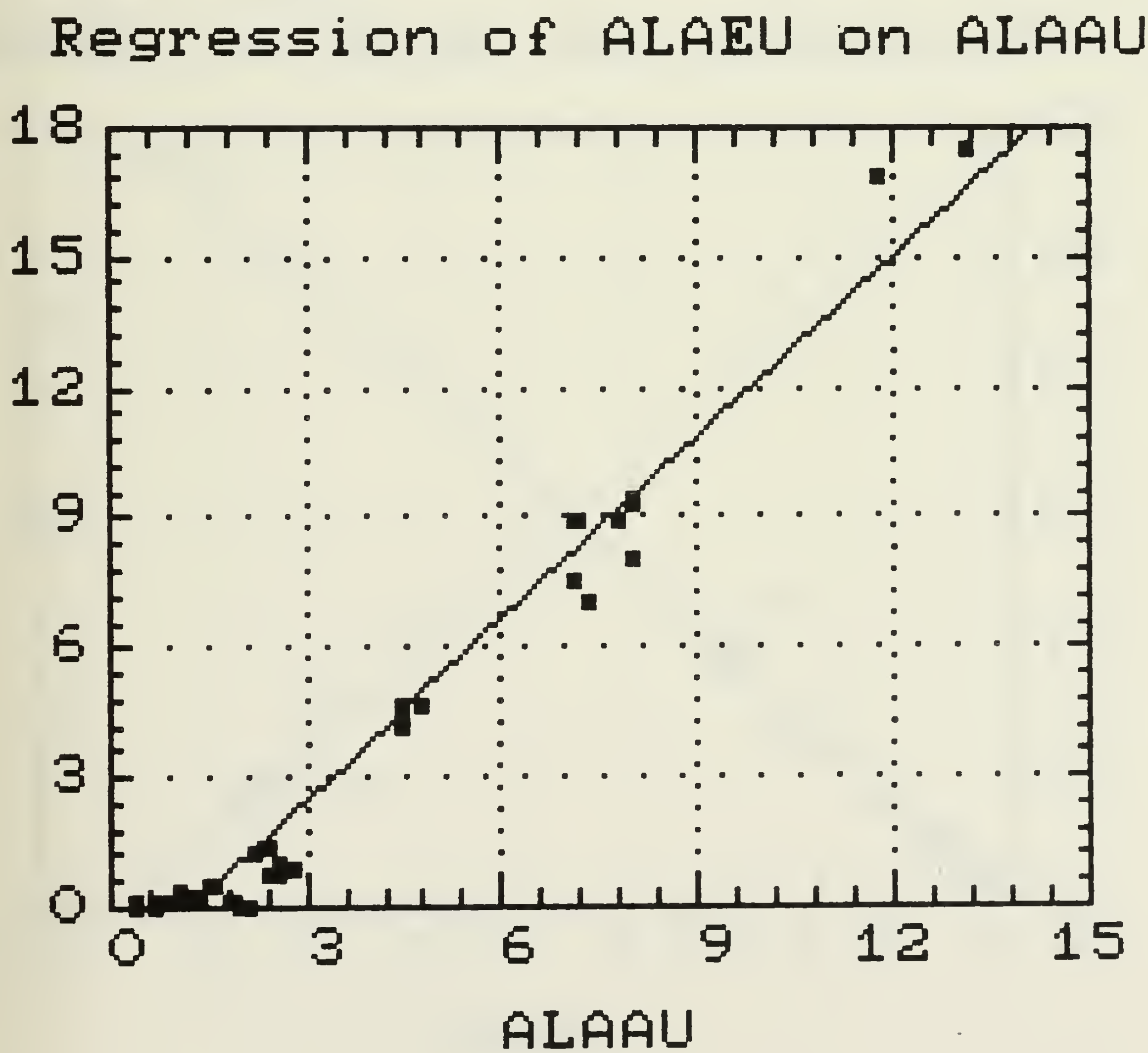



FIGURE 3.13

Simple Regression of CRAEU on CRAAU

| Parameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| Intercept | - 0.200179 | 0.105841 | - 1.89132 | 0.0654911 |
| Slope | 1.3806 | 0.0386803 | 35.6926 | 0 |

Analysis of Variance

| Source | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| Model | 306.0493 | 1 | 306.0493 | 1273.9624 |
| Error | 10.089834 | 42 | .240234 | |
| Total (Corr.) | 316.13909 | 43 | | |

Correlation Coefficient = 0.983913
Stnd. Error of Est. = 0.490137

Regression of CRAEU on CRAAU

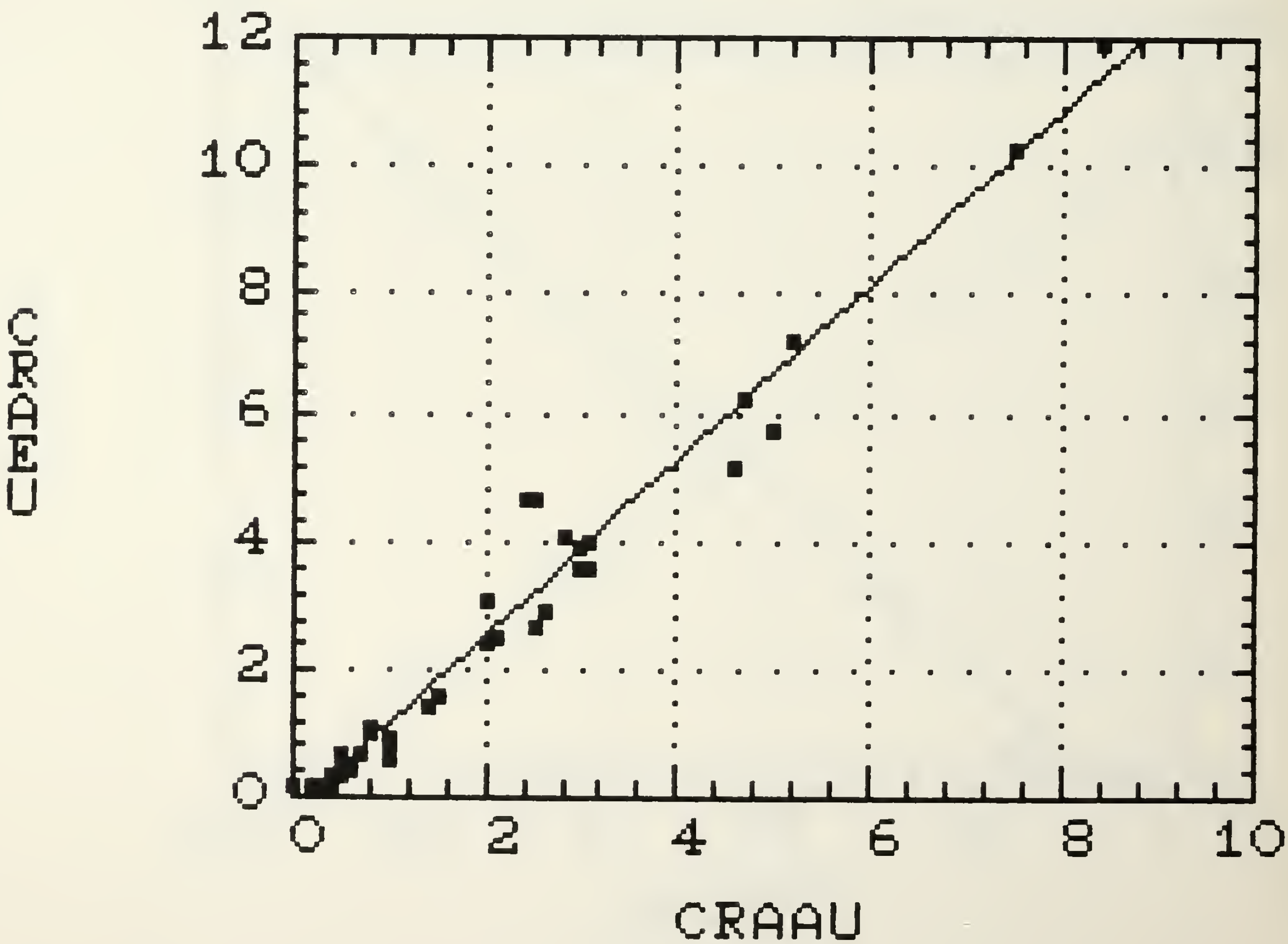



FIGURE 3.14

nple Regression of CUAEU on CUAAU

| rameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| tercept | -0.438072 | 0.444134 | -0.986352 | 0.329609 |
| ope | 1.73787 | 0.0443479 | 39.1872 | 0 |

Analysis of Variance

| urce | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| del | 5195.9963 | 1 | 5195.9963 | 1535.6369 |
| ror | 142.11162 | 42 | 3.38361 | |
| tal (Corr.) | 5338.1080 | 43 | | |

rrelation Coefficient = 0.986599
d. Error of Est. = 1.83946

Regression of CUAEU on CUAAU

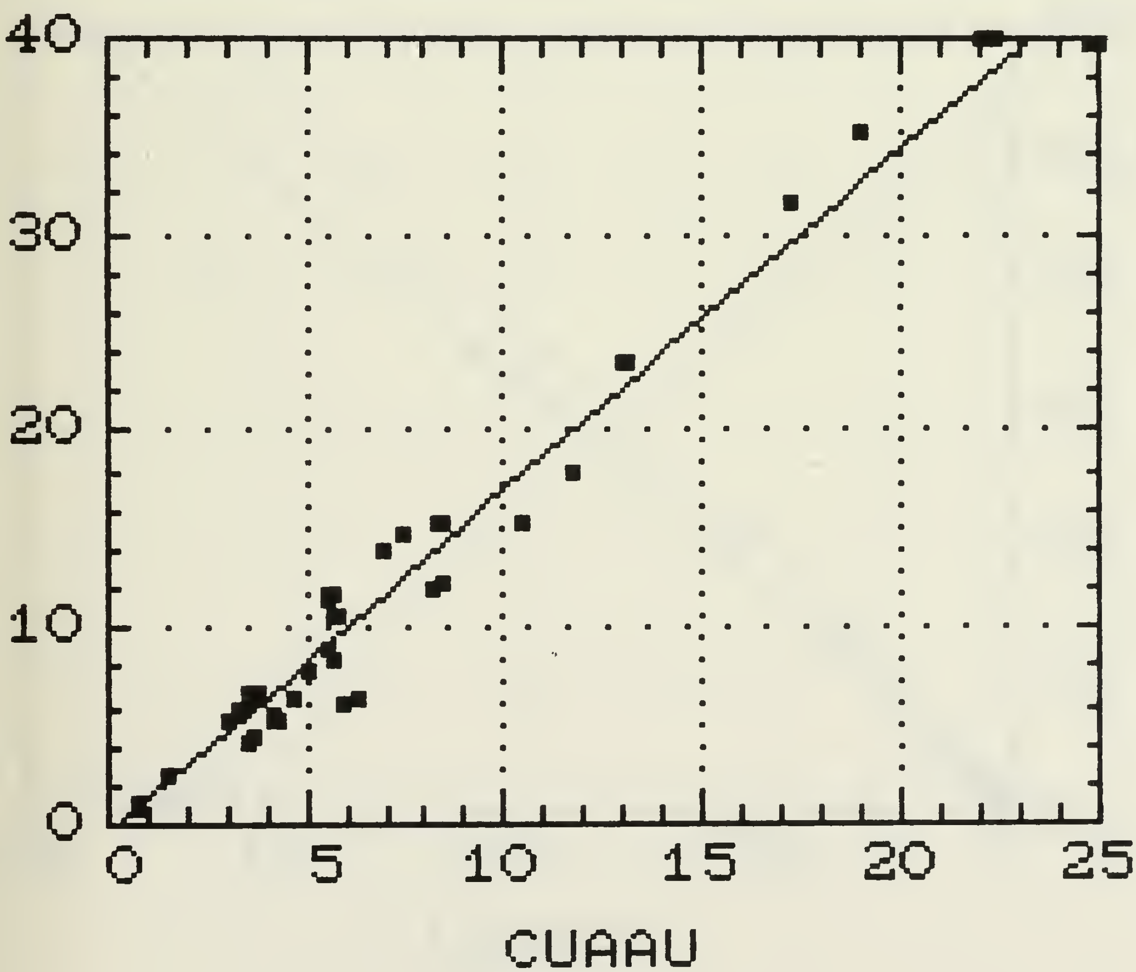



FIGURE 3.15

Simple Regression of MGAEU on MGAAU

| Parameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| Intercept | 1.9395 | 1.28588 | 1.50831 | 0.138962 |
| Slope | 1.57821 | 0.053623 | 29.4315 | 0 |

Analysis of Variance

| Source | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| Model | 36566.550 | 1 | 36566.550 | 866.215 |
| Error | 1772.9960 | 42 | 42.2142 | |
| Total (Corr.) | 38339.546 | 43 | | |

Correlation Coefficient = 0.976604
Stnd. Error of Est. = 6.49724

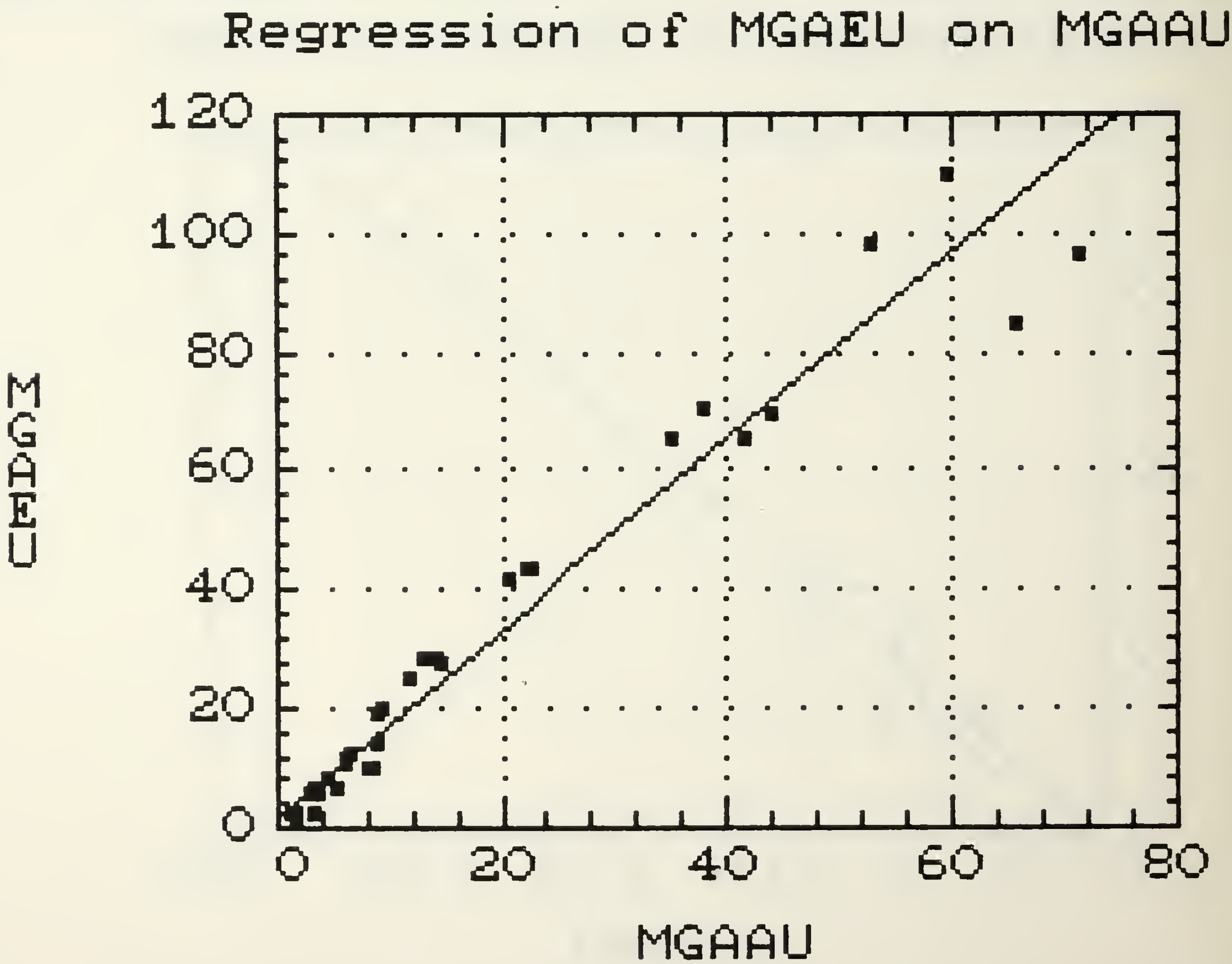



FIGURE 3.16

ple Regression of SIAEU on SIAAU

| ameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| ercept | − 2.03147 | 0.831418 | − 2.44338 | 0.0188345 |
| pe | 1.63664 | 0.0617822 | 26.4905 | 0 |

Analysis of Variance

| rce | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| el | 13050.187 | 1 | 13050.187 | 701.747 |
| or | 781.06236 | 42 | 18.59672 | |
| al (Corr.) | 13831.250 | 43 | | |

relation Coefficient = 0.971354
d. Error of Est. = 4.31239

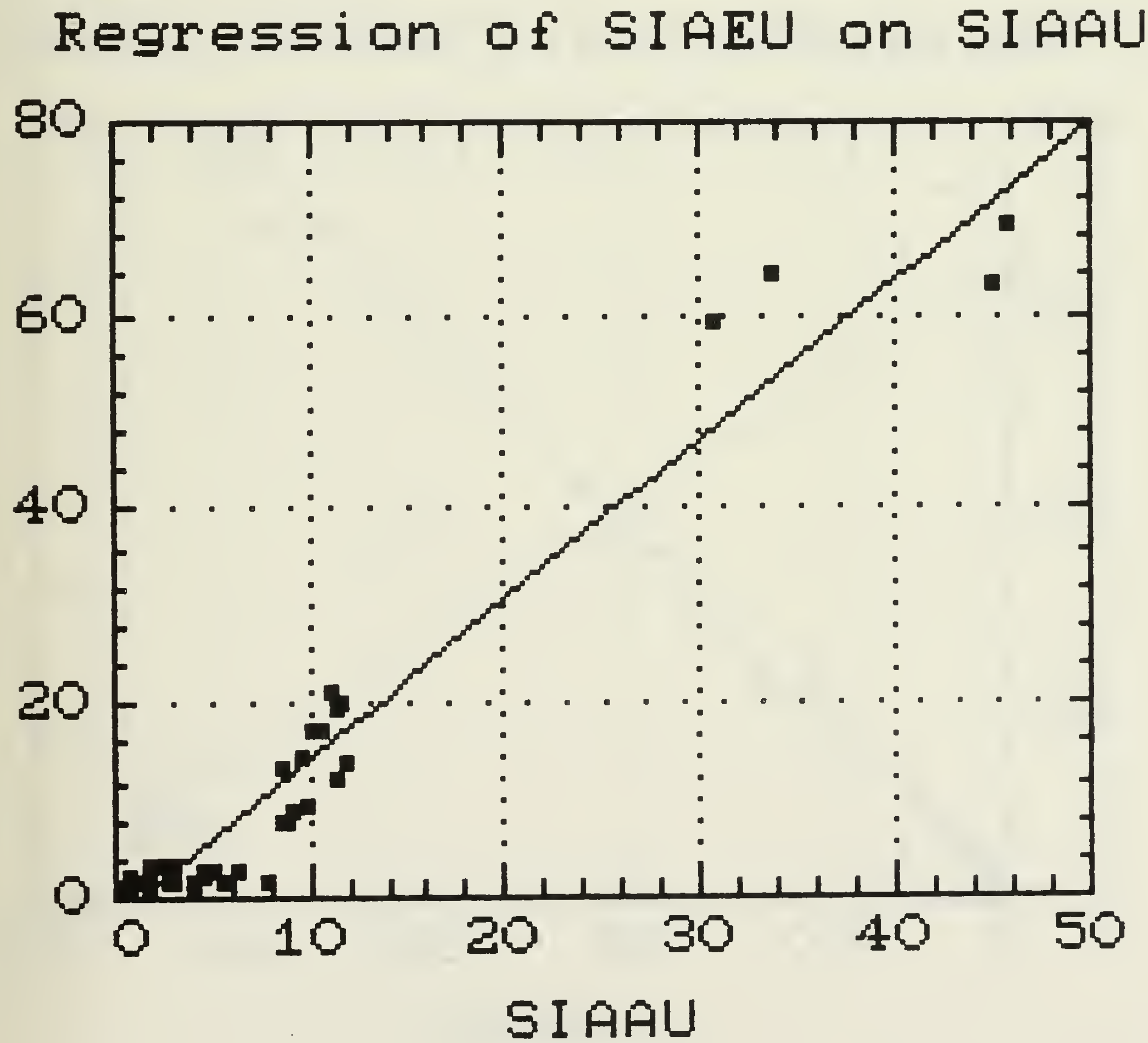



FIGURE 3.17

Simple Regression of TIAEU on TIAAU

| Parameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| Intercept | 0.0422875 | 0.40376 | 0.104734 | 0.917085 |
| Slope | 1.94904 | 0.0305722 | 63.7519 | 0 |

Analysis of Variance

| Source | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| Model | 21000.315 | 1 | 21000.315 | 4064.309 |
| Error | 217.01429 | 42 | 5.16701 | |
| Total (Corr.) | 21217.329 | 43 | | |

Correlation Coefficient = 0.994873
Stnd. Error of Est. = 2.27311

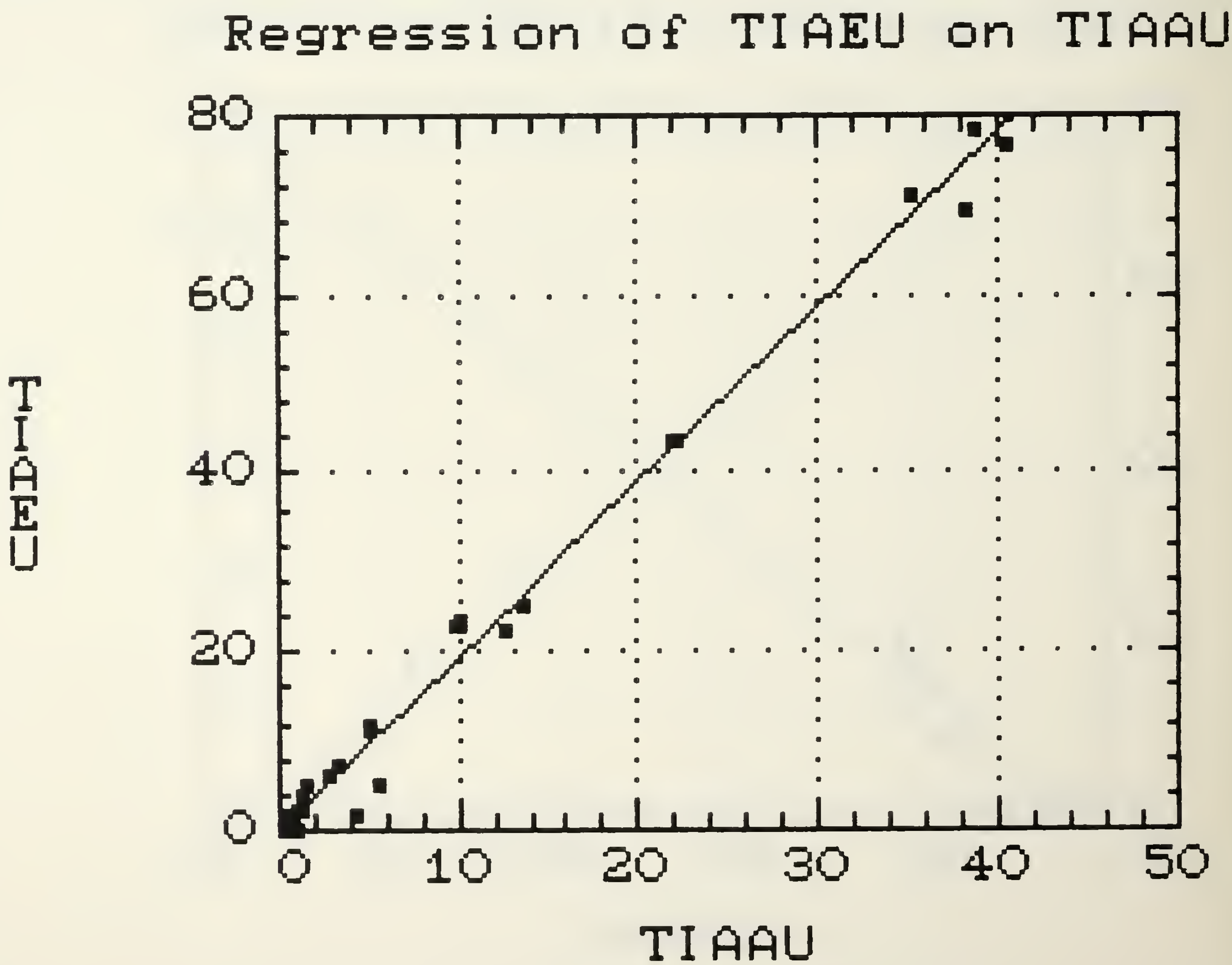



FIGURE 3.18

mple Regression of MOAEU on MOAAU

| rameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| tercept | 0.84626 | 0.123492 | 6.85273 | 2.36143E-8 |
| ope | 1.00588 | 0.0607666 | 16.5531 | 0 |

Analysis of Variance

| urce | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| del | 137.29742 | 1 | 137.29742 | 274.00659 |
| ror | 21.045083 | 42 | .501073 | |
| tal (Corr.) | 158.34250 | 43 | | |

rrelation Coefficient = 0.931177
nd. Error of Est. = 0.707865

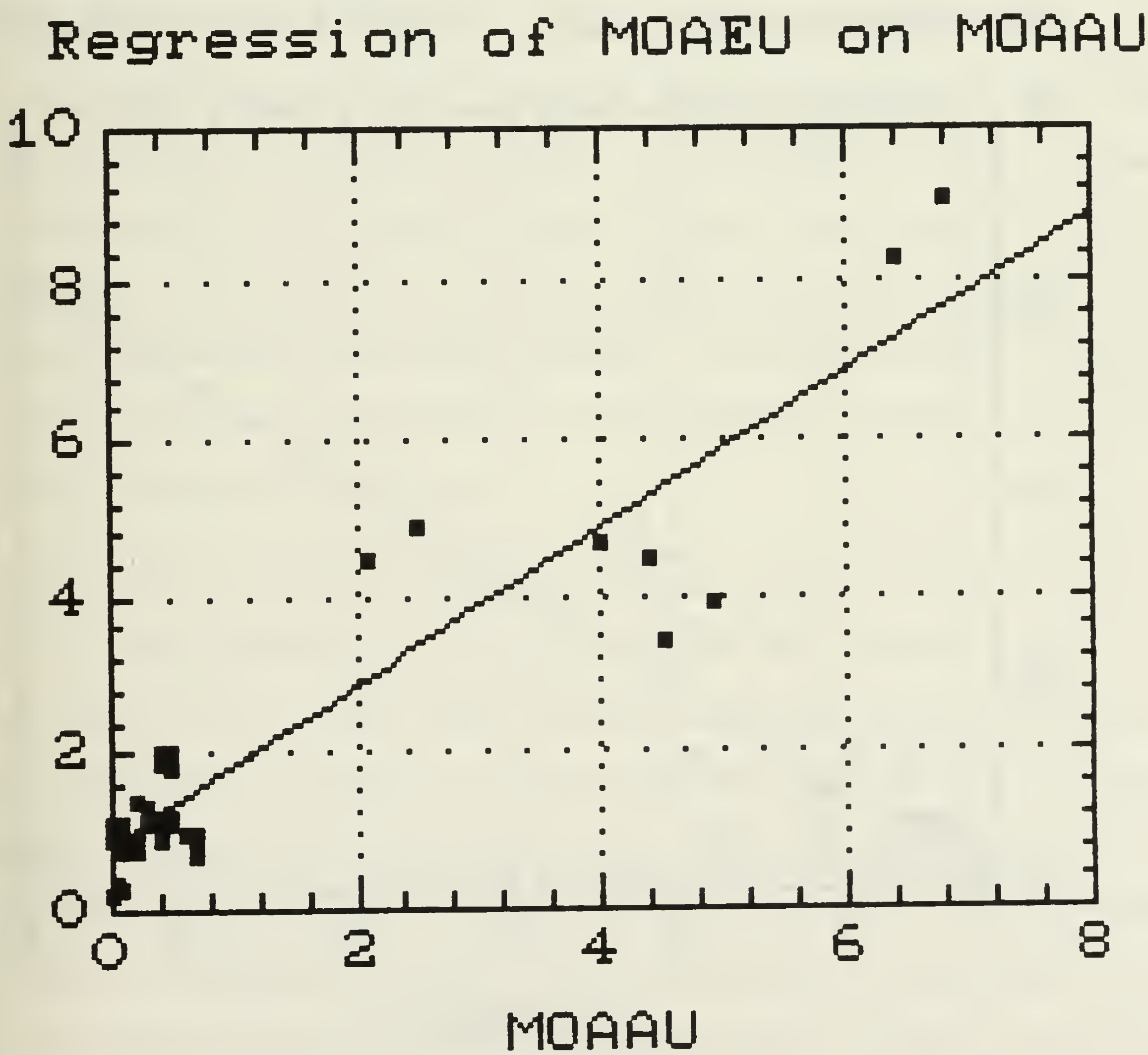



FIGURE 3.19

Simple Regression of NIAEU on NIAAU

| Parameter | Estimate | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| Intercept | 0.0181308 | 0.178004 | 0.101856 | 0.919356 |
| Slope | 1.05014 | 0.105428 | 9.96076 | 1.26166E-12 |

Analysis of Variance

| Source | Sum of Squares | Df | Mean Square | F-Ratio |
|---|---|---|---|---|
| Model | 70.812109 | 1 | 70.812109 | 99.216835 |
| Error | 29.975846 | 42 | .713711 | |
| Total (Corr.) | 100.78795 | 43 | | |

Correlation Coefficient = 0.838203
Stnd. Error of Est. = 0.844814

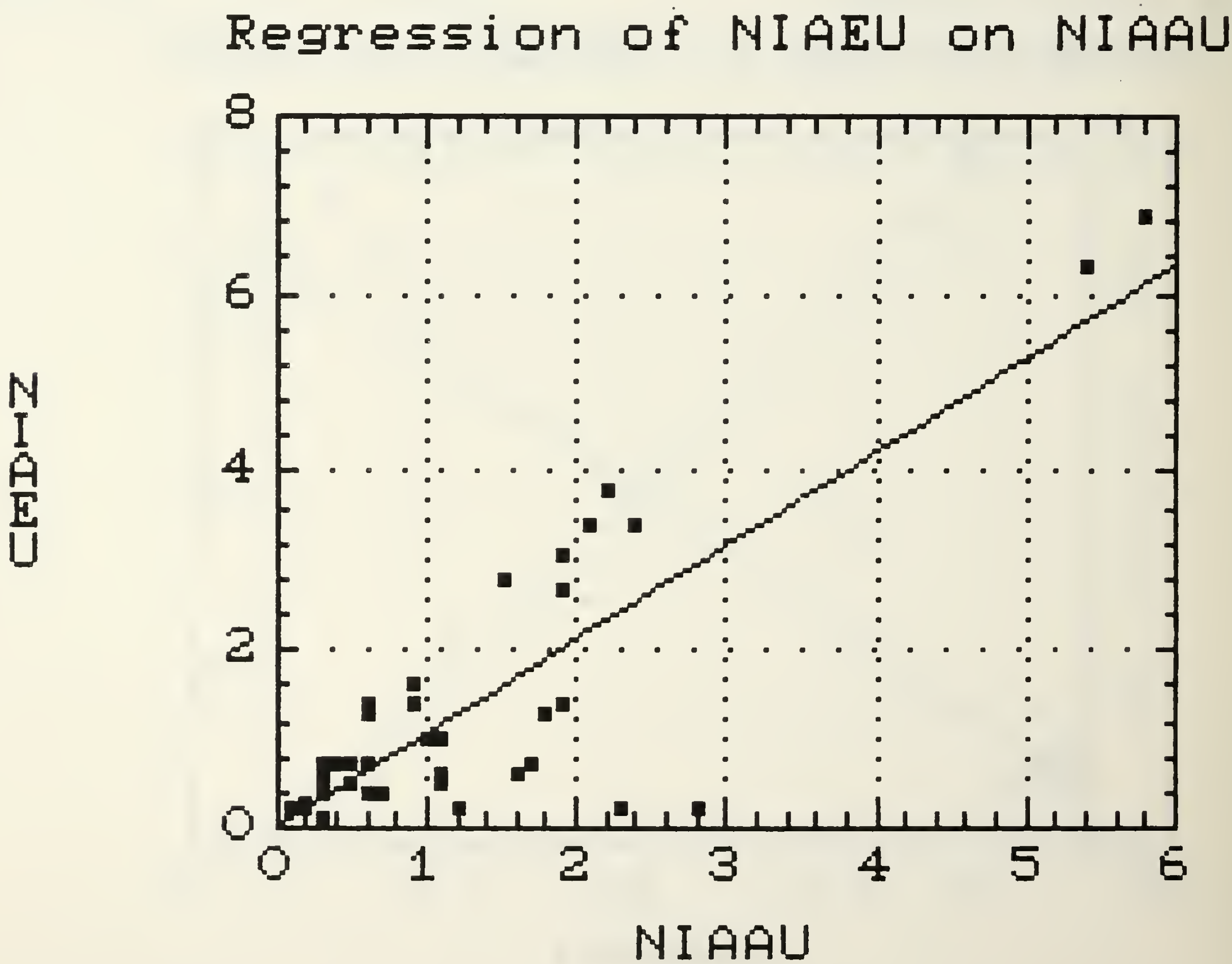



FIGURE 3.20

## 4.1 OAP LABORATORY MANAGER

The Systems Control Technology, Inc., under contract with the Air Force developed a software package known as CEMS IV (Comprehensive Engine Management System - Phase IV) to computerize the acquisition, recording and analysis of certain aircraft performance data critical for maintenance decisions. One segment of the CEMS IV system deals with the acquisition and maintenance of the oil analysis data for all the aircraft at an Air Force base. The oil analysis results are automatically acquired, by a Zenith Z-100 microcomputer, from the spectrometer (A/E35U-3) via an RS-232 interface; at the option of the oil laboratory technician the data can be written to an appropriate file for archival, and/or perform certain diagnostic tests to determine if the results indicate the need for maintenance actions. It is expected that this system will eliminate the time consuming aspects of manual data transcription and maintenance of records and will allow the technician to concentrate on the decision making aspects of the SOAP program. A prototype version of the package has been installed at the Barksdale Air Force base and is being used by the oil laboratory personnel at the base.

The CEMS IV system is designed to automate only the acquisition and recording of the data from used oil samples drawn from aircraft engines. In an oil laboratory, on a daily basis, several synthesized samples are analyzed on the spectrometer for purposes of daily standardization, offset check and adjustment or complete calibration and once a month several oil samples supplied by JOAP-TSC are analyzed for laboratory certification. CEMS IV does not deal with these oil laboratory functions. The Systems Control Technology, Inc., has just completed the development of another software package, as an adjunct to CEMS IV, to automate the above mentioned functions. The package, called OAP Laboratory Manager, has six modules to computerize the following routine laboratory functions: (1) prepare for standardization (2) daily standardization check (3) offset check and adjustment (4) complete verification of calibration (5) laboratory certification/correlation and (6) review standardization data.

We were tasked to provide technical consultation to the Air Force at the design review sessions during the development process and to generate test data to ensure that the software performs according to specifications. We participated in several design review meetings and made suggestions and recommendations to improve the presentations and displays. The OAP Laboratory Manager was tested by the oil laboratory at Barksdale Air Force base on November 5, 1985. The package was also excersized using several sets of test data generated by us. A few bugs were detected and some new suggestions for improving the presentations on the Z-100 microcomputer evolved. SCT, Inc., is now in the process of correcting the bugs and make software changes to incorporate some of the new suggestions.

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[4] Culler, A.F., Jr. "Engineering Services Applicable to SOAP, Task 5 - Development of Optimum Sampling Intervals" Southwest Research Institute Report No. 625, March 1975.

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